ASIAC

Report No. 187.1A

INTEGRATED DESIGN AND MANUFACTURING METHODS

VOLUME II - NEW HEURISTIC AND ARTIFICIAL INTELLIGENCE APPROACHES TO PRODUCTION SCHEDULING IN FLEXIBLE MANUFACTURING SYSTEMS

August 1987

Approved for Public Release; Distribution Unlimited

AEROSPACE STRUCTURES
INFORMATION AND ANALYSIS CENTER

OPERATED FOR THE FLIGHT DYNAMICS LABORATORY
BY ANAMET LABORATORIES, INC.

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Operated for the Flight Dynamics Laboratory by Anamet Laboratories, Inc.

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The engineering coordinator for this effort was William J. Craft (Associate Dean, School of Engineering). The principal investigators were Eui H. Park (Assistant Professor, Department of Industrial Engineering) and Samuel Owusu-Ofori (Assistant Professor, Department of Mechanical Engineering). Co-investigators were Steven H. Y. Lai (Assistant Professor, Mechanical Engineering), Celestine A. Ntuen (Assistant Professor, Industrial Engineering), Chin-Sheng Chen (Assistant Professor, Industrial Engineering), and Mohammed Belkhiter (Electronics Engineering-Data Processing, AMP, Westinghouse Electric Corporation, Winston Salem, NC).

The report on this investigation is presented in two volumes. Volume I discusses airfoil spline analysis for design and manufacturing, and was authored by Samuel Owusu-Ofori and Steven H. Y. Lai. Volume II, presented here, discusses new heuristic and artificial intelligence approaches to production scheduling in flexible manufacturing systems and was authored by Eui H. Park, Chin-Sheng Chen, and Celestine A. Ntuen.

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ABSTRACT

The need for an efficient economic production sequencing and scheduling (PSS) method for the flexible manufacturing system (FMS) has never been greater than it is today, due to the rapid increase in the complexity of the FMS.

In spite of the intensive studies that have been done in the PSS area, most of them are focused on optimal results to meet the due dates or to maximize the usage of the system. These solutions are found to be unsatisfactory for the real life FMS scheduling. In the real life scheduling problem, minimizing the costs is the first objective and the most considerable factor through as the multiple criteria (objectives) in measuring scheduling performance of a FMS.

This research proposes a new heuristic approach that adapts the above objective to PSS in an FMS environment by considering the following cost factors:

(1) Overtime costs.
(2) Lateness costs.
(3) Inventory costs.
(4) M/C idle time costs.

This heuristic approach will operate under an adjusted manufacturing lead time environment and scheduling flexibility (what-If conditions) which incorporates adaptive look-back and look-ahead rules.

When compared with some existing methods, the proposed method consistently shows lower total variable costs.

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TASK B: NEW HEURISTIC APPROACH TO PRODUCTION SCHEDULING IN FLEXIBLE MANUFACTURING SYSTEMS

CHAPTER I

INTRODUCTION

A Flexible Manufacturing System (FMS) is a production system consisting of a number of multi-purpose machines (work station) grouped together. Each work station is capable of performing multiple operation. For example, a work station could be a multi-purpose numerical control machine(s) or industrial robot(s). Work stations in an FMS are linked together by automated material handling equipment and controlled by computer system(s). If any work station in the FMS is out of service due to component failure or maintenance, the flexibility of the system allows the items in process to change the processing route to another work station, so the production can be continued without interruption.

1.1 Production Sequencing and Scheduling in FMS:

The sequencing and scheduling problem in the flexible manufacturing system has started to receive considerable attention in recent years. Sequencing is the determination of the order in which the operations are processed on the machines (work stations) While scheduling is the allocation of work stations to perform a given number of operations.

Production Sequencing and Scheduling (PSS) of the FMS involves a variety of operations processed through different work stations at the same time. Each operation could be processed through an alternate number of work stations, and each work station could perform more than one operation. Thus, the task of production sequencing in an FMS becomes more complicated than the production sequencing problem in the traditional job shop environment.

Some of the controllable constraints imposed on the PSS problem may be meeting the due dates, overtime limits, work-in-process inventory, number of working hours/day and costs. Uncontrollable constraints such as machining time, set up time and machine availability add to the problem complexity.

1.2 The Heuristic Approach:

In dealing with PSS in FMS environments, several optimization and heuristic methods have been proposed. Heuristic procedures are sometimes based on rules of thumb of solving some particular problems or some aspects of problems where an optimal solution is not desired or not possible due to computation a requirements. In this research, a heuristic procedure is presented as a solution approach.

Heuristic approaches in a PSS environment are usually based on "acceptability" rather than "optimality" criterion, of the environment, due to several simplifications and approximations to the problem situation. A basic advantage of the heuristic approach to problem solving is that it provides several solutions procedures that may generate several alternative solutions with little computational burden. Besides, the heuristic approach may be more practical than classical optimization approaches because of the knowledge of the "expert" on the problem situation.

Group technology (GT) application is used to enhance the PSS Heuristic approach. GT is the basis of work cell assignment in any FMS's PSS control. Therefore, a heuristic PSS which integrates the dynamics of job cellular structures will allow any PSS in an FMS environment to be more tractable, since multi-level scheduling tasks can be reduced to an entity type schedule based on GT profiles. Cellular job structures which operate on dynamic PSS heuristics are the major concern of the proposed approach.

1.3 Objectives:

Most of the PSS studies have focused on a simple capacity analysis with an emphasis on meeting the due date. Little consideration has been given to providing general facilities for representing and using any additional constraints.

Many researchers have focused on optimal results to meet the due dates or maximizing the usage of the system. These solutions are found to be unsatisfactory for the real life FMS scheduling problem [25]. In the real life scheduling problem, minimizing the production costs is the main objective and the most important considerable factor through a multiple criteria (objectives) in measuring the scheduling performance of FMS.

The objectives of this research are:

(1) To develop a new heuristic approach to PSS problem in an FMS environment.

(2) To test and validate the model with a prototype problem.

(3) To compare the results with some other available methods.

1.4 Scope and Limitations:

The heuristic approach in this research is concerned with the PSS problem in an FMS. The PSS problem in this research is a deterministic equivalent of a dynamic job shop problem.

1.5 Organization:

In Chapter II, a related and antecedent review of literature is presented. Chapter III contains a complete discussion of the heuristic model, assumptions, and procedures. Computer program inputs, outputs, limitations, and applications are discussed in Chapter IV, with an

example problem to validate the model. This problem is presented with both manual and computerized results. Also various uses of the computerized model and relative comparison with available models are discussed, (For more comparison results see appendix. The summary and recommendations for further research are discussed in Chapter V.

CHAPTER II

LITERATURE REVIEW

In this chapter, literature related to PSS in an FMS environment will be addressed through the following:

(A) PSS problems, objectives, and constraints

(B) Difficulties in implementing PSS for a FMS.

(C) Related heuristic approaches.

2.1 PSS Problems, Objectives, and Constraints:

The PSS problem has been intensively reviewed in literature. For example, (see, Day and Hottenstien [10], Buffa and Miller [5], Panwalker and Iskander [21], and Conway, Maxwell, and Miller [8]). In these writings it is suggested that the PSS problem is complicated by the extensive number of variations of work requirements, constraints of work stations, variable demands, due dates, and multiple objectives of job shop performance. Discussions have traditionally been centered on job shop scheduling. However, most recently, Sarin and Dar-El [25] have motivated a new line of concern over PSS in an FMS. The objectives of PSS have been given by Mize, White, and Brooks [8] as follows:

1. To maximize percentage of orders completed on time (i.e, meet the due date.)
2. To maximize the utilization of facilities and workers
3. To minimize in-process inventory
4. To minimize overtime, production, and
5. To minimize stockouts of manufactured items.

Translating the above objectives in terms of economic sense, the objective becomes "minimizing production costs".

2.2 Difficulties in Implementing PSS for an FMS:

Scheduling decision rules under a given objective are constrained by the following factors:
first, there are limits on the capacity of available resources, second, there are technological restrictions on the order in which tasks can be performed, and third, there are cost factors which control the priority releasing rules. Therefore, most scheduling models in the literature are usually concerned with questions such as:

- When will each operation be performed?
- In what order should the items be performed on the work station?
- What is the alternative schedule in case of having any changes in the system?
- What is the system status during the performance of each operation?

In general, these concerns have been observed by Sarin and Dar El [25] to constitute two main decisions: decisions on operations (items) sequencing (the orders of operations), and decisions on machine loading. A description of the necessary requirements for the integration of these two decisions in an FMS scheduling system has been discussed by Fox and Smith [12].

Rabbi and Park [11] have suggested at least two approaches to synchronizing a total production system concept in a cellular-structured production environment. These approaches are realizable components in most PSS in a FMS. The suggestions are as follows:

(1) A master production schedule is prepared for the end item presumably considering the available plant capacity and workload situation. However, an accurate picture of capacity requirement is not possible without MRP processing which in turn depends on the Master Production Schedule. As a result, a tremendous amount of replanning activities are generated for the production scheduler who must try to match the time phased requirements with the available resources.

(2) The MRP logic computes the timing requirement by utilizing lead time information. Lead time is usually estimated from the mean values of historical data which may contain in large proportion waiting time, unforeseen delays, and other unaccountable variances besides actual setup and processing time. Therefore, the timing information produced by MRP logic may not help improve the production efficiency. Furthermore, no provision has been provided for process changes which may drastically change the process lead time. The lot size also affects the processing time. Another method which can supplement Rabbi and Park's [11] suggestions is the rough cut capacity (RCC) technique (see, Moore [20]). The RCC uses information on items' due dates and bill(s) of material structure to calculate any one item's most likely job completion due date. These tentative "rough cut due dates" can then be used to experiment on trial bases when to release jobs for production.

The estimation of these dates is also based on the properties of each operation (item) and the expected queuing time on the workstations. Berry and Rac [3] reported the use of a "critical ratio" rule (CRR) as a measure of rough cut flexible lead times. The CRR considers time compared to remaining time to complete work, order due dates and queue time for work to be completed. For the most part, it is argued in the literature that the flexible lead time allows for dynamic release of jobs for processing thereby allowing for a prior decision during the design state of master production schedule.

2.3 Releasing Rules:

Releasing rules are various performance controls which determine the readiness of a job for processing. A comprehensive discussion of such rules appears in Panwalker and Iskander [23]. Relevant to the present research, the due-date rule is one of the releasing rules that has been discussed in much research.

Miyazaki [19] advocated a flowtime-based due-date rule (FTDD) of the following form:

$$d_j = r_j + p_j + m_j Q + z (m_j v)$$

where:

r_j denotes the job's release-date,
p_j is its processing time,
m_j is its number of operations, and
d_j is its due date.

The parameters Q and V (which are common to all jobs) are the means queueing time and the variance of queueing time, respectively, for a single-channel work station configuration, and z is a parameter that controls the tightness of the due-date. A remarkable comment on the above form has been made by Baker and Kanet [1].

In the derivation of Q and V given by Miyazaki, the assumptions are not stated explicitly. The equations suggest an assumption that jobs move through the queue in arrival order. However, this will not be the case when a priority rule is implemented. Therefore, Miyazaki's solutions for Q and V may be misleading estimates of the mean and variance of queueing time whenever priorities are based on due-dates rather than on order of arrival.

Reviewing the above equation, it can be seen that, in general, the structure of the rule is as follows:

<u>due date = release date + processing time + waiting allowance</u>

where the waiting allowance depends on the number of operations. This structure is quite similar to the processing-plus-wait (PPW) structure introduced by Kanet [2]. Experimental comparisons carried out by Kanet [1] and Baker [1] indicated that a more effective way to set due-dates is on the basis of total work content, or TWK. The TWK approach uses the form:

$$d_j = r_j + kp_j$$

(Where: k is a tightness parameter).

In fact, the comparisons in Baker [1] showed that TWK was consistently less effective than other policies only in conjunction with first-in first-out (FIFO) priorities. However, Miyazaki compared FTDD and TWK only in conjunction with FIFO. The TWK policy was not considered when the performance of more sophisticated priority rules was explored. A logical question is whether the FTDD policy would perform as well under due-date-oriented priorities.

A discussion of the use of releasing rules in FMS scheduling problems has been given in not [22]. The ratio rule, which schedules a part next on a machine if the ratio of its remaining production requirement to original requirement is larger than the ratio of the remaining production time to day's production time, was found to be better than the first come first served (FCFS), shortest remaining processing time (SPS) or largest remaining processing time (LPT) rules. An experimental study of the releasing rules is reported by Stecke and Solberg [27]. A priority rule which is based on dispatching the next part with the smallest ratio obtained by dividing the shortest processing time for the operation by the total processing for the part is reported to give better results than SPT, LTP or related priority rules.

Sarin and Dar-El [25] have proposed a heuristic algorithm to obtain a solution to the FMS scheduling problem within a prespecified range of desired machine utilization as a releasing rule index. Their proposition considers the aggregate flow of parts between machines and uses heuristic rules like FCFS, SPT and others to sequence consecutive parts on a machine. The advantage of the machine utilization rule is that machines are well utilized and effective routing can be readily approximated. In summary, the PSS problem in FMS's is ordinarily more complex than the usual job shop problem. The attention of the researchers in this line of endeavors is geared towards the relaxation of dynamic job shops rules to accommodate a FMS.

The new approach in this research is to contribute to these lines of endeavor. Thus, the model formulated in this research includes the utilization of the machines as a factor in priority releasing rules, due date rules, minimum cost rules and flexitime scheduling rules.

As this review shows, much of the development in the scheduling problem in FMS is yet to be done. The focus of this research will then be on developing a new heuristic algorithm in which all these constraints will be under consideration. In the next chapter that heuristic algorithm will be discussed in detail.

CHAPTER III

THE PROPOSED HEURISTIC MODEL

This chapter discusses a heuristic model for solving the PSS problem. The proposed model is based on an adaptive adjusted manufacturing lead time decision rule, with look - ahead & look - back capability. Minimizing total production costs is used as a measure of performance of the model. The following concepts and definitions will generate subsequent discussions:

3.1 Job Operation Concept:

The job (product's order) in this problem is defined as a collection of operations in which a special precedence structure applies, each operation, after the first, has a number of direct predecessors. And each operation, before the last operation, has exactly one direct successor. A variety of jobs are simultaneously processed through the work stations. A job's operations could use the same or different work stations except in the case where two operations from the same level (twins) of the bill of materials. In such a case, the operations must be processed at different work stations (simultaneously, if necessary).

3.2 Set up Time Concept:

Due to the flexibility of the work stations in performing multiple operations of different kinds, the machine time may vary form one work station to the other. Thus, an FMS is assumed to operate under a flexible set up time (FST) rule. Set up time would be defined by the manufacturer according to the different kinds of operations that could be processed at a work station. There are four different types of operations that could be performed at a work station such as turning, shaping, or grinding.

And each type has a specified code (1, 2, or 3), so that the absolute difference between the last operation's code (LOPC) and the next operations' code (NOPC) will determine which set up time category will be used. Set up times may be classified as minimum, normal or maximum set up times.

Under the minimum set up time rule, set up time is assumed negligible (i.e., lower bound of zero) if the new operation at the work station is the same kind of operation as the previous one, e.g. the new operation is going to use the same numerical control (NC) program, same tool, and same starting position/home on the computerized numerical control (CNC) machine. So there are no initial installations like loading programs, replacing tools or adjusting positions. Otherwise, normal flexible set up time (NFST) or maximum flexible set up time (MFST) rules are enforced.

Under the (NFST)/(MFST) rules, if the last operation code (LOPC) was of type "1" and the new operation code was of type "2" then the set up time for the new operation would be equal to the normal set up time. If the new operation code (NOPC) was of type "3" then the new set up time would be equal to the maximum set up time.

Table 3.1 is used to describe the flexible set up time rule described above.

Table 3.1 The FST Rules

/NOC - LOPC/	Set up time
0	Minimum
1	Normal
>1	Maximum

The following are the basic assumptions for the heuristic model.

3.3 Assumptions Concerning Jobs:

(1) Each job consists of specified operations, each of which is performed by only one work station and each operation has a predefined percentage of its job (unit product).

(2) Each operation could be in one of the following states during it's processing period.

a- "W"- waiting to be processed (if prerequisite(s) are not ready.

b- "R"- Ready to be processed.

c- "P"- Processing (operation is in process on work station).

d- "C"- Completed (operation has been completed).

(3) Operations that have the same parent item are not allowed to be processed at the same work station.

(4) Each operation has a flexible set up time.

(5) Each job has a complete prescribed bill of materials (technological order).

(6) Each operation has a specified machine time on each work station

(7) Each item has a standard identification calling code.

(8) Inventory cost factor is available for each item at any work station.

(9) In case of having defects, jobs are processed to completion using the most available item inventory stock.

3.4 Assumptions Concerning Shop (work stations):

(1) Each work station has its own specified capacity (regular time hours/day, maximum overtime hours allowed/day, working days/week).

(2) Shut down, maintenance or breakdown times are uniformly distributed throughout the processing period. This implies that a work station unavailability factor is known with certainty. This factor is assumed available for each work station as an input to the model.

(3) Each work station is capable of processing a maximum of four different operations simultaneously.

(4) Normal and maximum set up time for each work station is known or can be determined.

(5) The minimum set up time for each work station is equal to zero.

(6) No preemption is allowed; i.e., once an operation is started at a work station it must be completed before any other operation can begin at that work station.

(7) Infinite storage capacity is assumed.

(8) There is a terminal work station which performs the last operations of the jobs. That terminal work station could also perform some other specified operations besides the last operation.

(9) Overtime cost factor is available for each work station.

3.5 Dictionary of the model variable names:

The following are the definitions of the variables' symbols used to describe the proposed heuristic model:

(ATP_{mj}) = Actual time period needed to process the M^{th} operation on work station "j" at a given period i.e., including machine idle time.

(BPT_j) = Beginning of processing time on station "j".

BST = Daily start of calendar time in workstations.

C = A constant which represents production fixed costs (i.e. regular time machine and labor costs).

(CR_{ij}) = Total costs of processing operation "i" on the "j" th order in the arrangement.

CHDD = The due date of the operation's predecessor(s).

CTMT = twin's completion time.

DCOST = Delay costs/unit.

(EDD_{kj}) = Estimated due date for the raw material operation (RMO) on work station "j".

(ELT_{jk}) = estimated lead time for (RMO_k) on work station "j".

EPC = Estimated processing costs.
= min (inventory cost(s) + overtime costs + C) of different arrangements on work stations.

(EPT_k) = Estimated processing time of (RMO_k)
= Normal set up time + regular machining time.

(EPT_{sk}) = Estimated processing time of successor "s" of (RMO_k)

(EQT_k) = Estimated queuing time of successor "s" of (RMO)

(EQTsk) = Estimated queuing time of successor of "s" of (RMO)

HCOST = Total holding costs rate (expressed per holding period)

HTCOST = Total holding costs of the processed item.

ICF = Inventory costs factor.

ICFT = Inventory cost factor of the processed twin item.

(Idletm) = Idle time on station "j".

IDCOST = Idle time costs.

IDCF = Idle time cost factor.

IQTYT = Quantity of the twin item needed.

JDCF = Job delay cost factor.

JDD = Job due date.

L = Number of all successors of (RMO).

LPT_j = Last processing time on work station "j".

$(LTIME_{kj})$ = Lateness time of completing operation "k" on work station "j".

M = Number of ready operations (R) on a work station at a given period. (M < 4).

$(MAET_{jd})$ = Maximum allowable ending time on station station "j" at day "d".

MH = Regular machine hours.

(MH_{ij}) = Machine hours needed to produce one item of (R_i) on work station "j".

n = Number of (RMO) in the job order.

N	=	Maximum number of work stations in the model (N = 9)
(NST_j)	=	Normal set up time of work station "j".
OTCF	=	Overtime cost factor.
OTCOST	=	Overtime costs.
(PVC_{kj})	=	Production variable costs due to processing an (R) operation "k" using (RT) hours bases.
QCOST	=	Queuing costs.
(QF_j)	=	Queuing factor on work station "j".
(QTM_{kj})	=	Queuing time of (R) operation "k" on work station "j".
(QTY_{ij})	=	Quantity of (R_i) needed by work station "j".
RFJ	=	Remaining fraction of the job.
RFJT	=	Remaining fraction of the twin's job.
(RTM_{kj})	=	Release time of (RMO_k) on work station "j".
(STM_{kj})	=	Starting time of job "k" on work station "j".
(T_j)	=	Summation of actual processing time needed to process the "M" operations on work station "j" at a given period.
($TNOW_j$)	=	current available time on work station "j".
τ	=	Machine cycle time
	=	1 / production rate.
($TPVC_j$)	=	Total Production Variable Cost using overtime (OT) or regular time (RT) hours bases.

3.6 The Heuristic Model:

The main decision criteria that motivates the model are:

(1) When to release the raw materials to start processing the job.

(2) Which operation to process first on the work station.

Fig 3.1 shows a schematic model of the main elements involved in the model.

demand forecasting GT bill of material

work station data

master production schedule

priority cost factors

material requirements planning

Minimum Cost Factor Releasing (MCFR) rule

operations time table on each work station

Fig 3.1: Schematic model of the main elements involved in proposed model of the PSS problem in an FMS.

A discussion related to the above two criteria follows.

3.6.1 When to Release Raw Materials to Start the Job:

A flexible lead time approach has been used to take care of the above criterion by applying the rough cut capacity (RCC) technique. The (RCC) is a technique used to estimate the production capacity needed for operations.

Flexibility of lead time could be maintained by considering the job's due dates with the following factors:

(1) Quantity needed (QTY).

(2) Expected processing time for each operation (EPT).

(3) Queuing factor on each work station(QF).

The release date(s) of the job(s) could be estimated by using the relation:

$$(RTM_k) = JDD - [EPT_k + EQT_k + \underset{S=1}{L} (EPT_{sk} + EQT_{sk})] \ldots . (3.1)$$

Where, $k=1, \ldots . . n$

3.6.2 Which Operation to Process First on the Work Station:

The minimum cost factor releasing (MCFR) rule with look - ahead & look - back techniques has been formulated to address the above criterion. The MCFR rule is a decision rule which releases type "R" operations into the work stations based on the minimum expected processing cost (EPC) of all the possible arrangements of "R" operations of each work station.

The released operation on a work station is the first (R) operation of the arrangement which has the minimum EPC. To illustrate this rule, suppose there are three ready operations on a work station, R1, R2, R3. Then, the question is which one to process first. First, the expected minimum total cost of processing operation R1 first on the work station is given by:

$$\min.\ [(CR_{11} + CR_{22} + CR_{33}),\ (CR_{11} + CR_{32} + CR_{23})] \ldots\ldots (3.2)$$

Where:

CR_{ij} = Total costs of processing operation "i" on the jth order of the arrangement.

Second, the first operation of the arrangement which has the minimum EPC, will be selected as the best candidate to be processed first on the work station, i.e.:

$$\begin{aligned} \text{Min. EPC} = \text{Min}\ [&\text{Min}\ [CR_{11}+CR_{22}+CR_{33}),(CR_{11}+CR_{32}+CR_{23},]],\\ &\text{Min}\ [(CR_{21}+CR_{12}+CR_{33}),(CR_{21}+CR_{32}+CR_{13})],\\ &\text{Min}\ [(CR_{31}+CR_{12}+CR_{23}),(CR_{31}+CR_{22}+CR_{13})]] \end{aligned}$$

If minimum EPC is equal to (CR21+CR12+CR33), say, then the candidate operation is "R2". Note that operation "R1" which comes in the second position, may not be the next incumbent operation to be processed after "R2", due to the possibilities of having some more operations "ready" during the processing period of operation "R2". In this case the (MCFR) is applied again on a set of "R"'s. A flow chart in Fig 3.2 shows the overall logic of the (MCFR) rule.

Set Work Station Index [i = 1]

Is
the work station available
now?

No

Yes

Identify the work station constraints and variable values. Then calculate and identify the set of "R" on it.

Calculate min. EPC of the whole possible arrangements of " R " on the work station, when the first position is fixed with one of the " R " 's.

Repeat the last iteration for the same " R " operations (R-1) times, by fixing another " R " operation on the first position each iteration.

Sort the min. EPC's & select the min. Then select the first operation of the arrangement which has the min. EPC.

Change th status of the selected operation and start processing. And remove that operation form " R " set.

Are there
more stations
left?

Yes

Increase
work station
# by 1 i.e.
i=i+1

No

All operations completed?

Yes

No

Fig. 3.2: Logical flow chart of the (MCFR) rule.

3.7 The general procedures of the algorithm:

Step 1

Apply the (RCC) rule to estimate the due dates for each operation schedule using the due dates information on the job(s).

Step (1.1)

Estimate the due date of each operation's predecessor(s) starting from the last operation of the job using the model:

$$CHDD = JDD - EPT \quad \ldots\ldots\ldots\ldots(3.3)$$

Where:

$EPT = NST + MH$

$MH = QTY * \tau$

Step (1.2)

Estimate the raw materials release (arrival) calendar time(s) for that job (ATM).

Step (1.3)

Repeat the above steps for each individual job released for production. The logic flow chart of this step is shown in Fig 3.3

Step 2

Estimate the release date(s) of the job(s) using the relation:

$$(RTM_{kj}) = (EDD_{kj}) - [(X_{kj})*(Q_jF)*(EPT_{kj})] \quad \ldots.(3.4)$$

Where:

$i = 1,2,3....M$

$j = 1,2,3....N$

$k = 1,2,3....n$

Furthermore;

$$(QF_j) = (ATP_j)/Max(ELT_{ij}) \quad \ldots\ldots\ldots(3.5)$$

$$(ATP_{jt}) = (LTP_{jt}) -(TNOW_j)\ldots\ldots\ldots(3.6)$$

where "t" represents (T)

and $(LPT_{jt}) = (TNOW_j) + (T_j)$ ....(3.7)

$(T_j) = ((QTY_{ij}) * (MH_{ij}) + (NST_j)$...(3.8)

$(ELT_{kj}) = (EDD_{kj}) - (TNOW_j)$........(3.9)

* If (TNOW) = 0 ----> then, (TNOW) = min (ATM_{kj})

<u>Step 3</u>

Apply the minimum cost factor rule to select the candidate operation on the work station, as follows.

<u>Step (3.1)</u> Calculate and identify the set of "R" on the work station.

<u>Step (3.2)</u> Get a ready operation "R" on the work station.

<u>Step (3.3)</u> Calculate the operation's expected processing time (EPT).

<u>Step (3.4)</u> Assign the possible starting time (STM) of the operation according to ATM and TNOW:

If $(ATM_{kj} < TNOW_{kj})$ ----> $STM_{kj} = TNOW_{kj}$.

If $(ATM_{kj} > TNOW_{kj})$ ----> $STM_{kj} = ATM_{kj}$

$TNOW_{jk} = ATM_{kj}$

<u>Step (3.5)</u> If (STM - ATM) > 0

then;-----> $QCOST_{kj} = (STM_{kj} - ATM_{kj}) * (HCOST_{kj}/hr)$.

------> $IDCOST_{kj} = 0$

otherwise;----> QCOST = 0

$$IDCOST = (MAET_{d1} - TNOW_{d1}) + \sum_{t=(TNOW_{d2})}^{t=(TNOW_{d1})} E * t + [(ATM - BPT)]$$

Where: E = 1 if the day is a working day.

= 0, otherwise.

And: d2 = day when the operation is ready on the station.

d1 = day when the station is available.

$(IDCOST_{kj}/hr) = IDLETM_{jk} * IDCF_j$

$(QCOST_{kj}/hr) = (IQTY_{kj} * COP_{kj} * ICF_{kj}) / 100$

Start

Identify the due date for a given job.

Estimate the processing time of the last operation in the given job.

Apply RCC rule to estimate he last operation's child schedule due date.

Calculate the EPT of each child predecessors and do the next iterations for each predecessor individually till pointer A.

items due dates are estimated?

No

Estimate the new predecessor(s) due date:

NCHDD = CHDD-EPT

Yes

Estimate the arrival time (ATM) of each operation on it`s Work station.

Yes

More jobs?

A

No

Fig: 3.3 Logic flow chart of step (1).

Step (3.6) Calculate the operation completion time (CTM)

$$CTM_{kj} = STM_{kj} + EPT_{kj}$$

Step (3.7) If (EDD - CTM) > 0

----> Earliness Costs = (EDD-CTM) * (HCOST/hr)

----> Lateness Costs = 0

If (EDD - CTM) < 0 --> Lateness Costs = (CTM-EDD)*(JDCF/hr)

--> Earliness Costs = 0

Where: HCOST/hr = (IQTY * COP * ICF)/100

: JDCOST/hr = (IQTY * COP * JDCF)/100

Step (3.8) If the operation (R)'s twin has been performed; then calculate holding costs for that twin operation (HTCOST) under the look - back rule.

i.e. If (CTMT - CTM) < 0

------> $HTCOST_{kj} = (CTM_{kj} - CTMT_{kj}) * (HTCOST_{kj})$

Where: $HTCOST_{kj}/hr = (IQTYT_{kj} * COPT_{kj} * ICFT_{j})/100$

Step (3.9) Calculate the total production variable costs (TVPC)of the operation using regular working hours bases (RT)

(TPVC) =

QCOST + Earliness/lateness costs + HTCOST + OTCOST + IDCOST

Where: OTCOST = (OTCF * OT hrs)

OT hrs = $(CTM - CTM_{RT})$ working hours

OT

Step (3.10) If (CTM - EDD) > 0 then: use the overtime bases and get the total production variable cost again $(TPVC_{OT})$, using the same sequences as above, otherwise, $(TPVC_{OT})$ is not considered

Step (3.11) Identify the min. $(TPVC_{RT}, TPVC_{OT})$ and indicate whether it was OT or RT when using overtime bases or regular time bases. $TPVC = min.(TPVC_{RT}, TPVC_{OT})$

Step (3.12) Do the above iterations for the whole possible arrangements of the set "R" starting from 3.2 and keeping the first operation fixed in the first position, by doing the necessary adjustment of the current time on workstation

i.e. TNOW = CTM_{RT} or CTM_{OT}

Step (3.13) Select the minimum arrangements TPVC of all the arrangements when the first item was fixed in the first position. (Min. TPVC), Where:

$i=1,\ldots.M$ & $M=\#$ of "R" operations at work station.

Step (3.14) Change the position of the first operation and replace another operation in the first position. And, repeat the above iterations starting from (3.2) until each operation has a chance to occupy the first position in an arrangement set once.

Then, compare between the (Min. TPVC)'s and identify the Min. [(min..TPVC)] to determine if overtime or regular time bases have been used. The first item of that arrangement is the next item to be processed at that work station.

Mathematically, The objective function of step 2 could be written as:

$$\text{Min. (min. } TPVC_{ij}) \text{ ....(3.8)}$$

Where:

$$i = 1,\ldots..M$$
$$M = \# \text{ of "R" on w.s.}$$
$$= 4$$

Step 4

After identifying the candidate operation (P) at the work station "j", based on whether overtime bases are needed or not, use the original time on work station "j" and calculate the completion time of (P) using the relation:

$$(CTM_p) = TNOW_j + EPT_p \text{ ....(3.9)}$$

Then, adjust the main clock on work station "j" so that;

$$TNOW_j = CTM_p$$

Special case:

If $(ATM_p < TNOW_j)$ and (p) is a raw material operation,

Then $ATM_p = TNOW$ and $STM_p = TNOW_j$

Step 5

Repeat steps (3) & (4) until completing the operation of at least one job.

Step 6

Check for "R" incumbent jobs, apply MCFR to release the candidate job for processing "P", and go to step 1. If there are no more jobs to add, and some jobs are still not completed, go to step 3; otherwise stop.

Special case:

In step (2); If ($RTM_k < TNOW_j$) then ----> $RTM_k = TNOW_j$

In this case a delay from JDD most probably will occur. By applying the MCFR rule (step 3), the decision will be made whether or not to operate for overtime hours and try to meet the due date and/or minimize the delay.

3.8 Which lot sizing technique is used in the model?

Because of the dynamic nature and the mid-volume production situation involved in the FMS scheduling problem, the lot-for-lot (discrete ordering) lot sizing technique was used in the model.

The use of this technique helped in simplifying the process to approximate the lead time through each individual period of the production run by using the RCC technique. Also, it helped in minimizing the inventory carrying costs by providing period by period coverage of net requirements, while the dynamic planned order quantities always equal the quantity of the net requirements being covered. In the next chapter, a brief explanation of the computer program, its inputs, outputs and limitations are presented. Also, some example problems on the above model will be illustrated.

CHAPTER IV

THE COMPUTER MODEL AND NUMERICAL EXAMPLE

4.1 The Computer Program:

The developed computer program for the proposed algorithm contains more than 1000 lines and 15 subroutines. It works on DEC-10 system, and contains 102 blocks. The main objective considered when designing the program was to minimize the "Ram" memory used by the program. This was accomplished by minimizing the use of arrays in the program. Random access data files were used to store, retrieve and update the information as needed. This technique makes it feasible to apply the model using micro computers where the memory size is one of the main consideration factors when using these systems.

The program is designed to run continuously, so it is always expecting a new job to be entered after completing a job. The user could end the run by not supplying the model with any more jobs. Then, the program will be stopped after scheduling the last existing jobs in the shop (model).

The program could also be used for the analysis purposes, i.e., to answer the what-it-conditions by changing the different variables and cost factors which control the work stations' time table.

Also, there is a double check on the input data to the items data files so that mistyped or wrong data would be checked and updated before it could be used in the model.

4.2 Input Data:

The input data are mainly divided into two main parts:

a - Data concerning the work station (work data files)

b - Data concerning the jobs coming to the shop (items data files)

4.2.1 Work Stations Data Files

For each work station, the user has a choice between using the old data of the work station or updating it. The following is the data needed concerning the previous status of the work station:

- a - The identification code of the last items processed on the work station
- b - When it was completed
- c - What type was the last operation (1,2, or 3)?
- d - The cumulative idle time on the work station

The other part of the work stations' data files data is permanent, at least for one production period. It includes the following:

- a - work station set-up times (normal, maximum)
- b - work station capacity (RT,OT, unavailability factor, working days/weeks, maximum operational capacity)
- c - Cost factors (idle time, overtime)

An example of the work stations' data file input data is shown in appendix A.

On each work station data file there is a dynamic calendar timer. It is able to go backward and/or forward to meet the flexibility requirements of the model. That calendar takes under consideration the different changes from overtime bases to regular time bases and vice versa. The actual overtime hours (if any) and the actual M/C idle time hours (if any) are also being taken care of according to each work station's capacity [working days/week) and working hours/day (RT & OT)].

The calendar does not consider the 29th day of February, so it could work continuously for 4 years without adjustment.

4.2.2 Item's Data File:

The input data concerning the jobs coming into the shop are stored in the item's data file. The user has a choice of using an old data file or a new data file.
When using an old data file it is possible to store the new information after the existing information or to write over this information. Each item in the model has a 4 digit identification (ID) calling code. The item's ID calling code is the only way to distinguish and retrieve the item's record from the item's data file. The item's ID # contains 4 digits in the model and could be extended (if needed) by doing some adjustments in the computer program. An example of the item's data file is shown in appendix A.

4.3 Outputs:

There are three different kinds of outputs generated by the program. The first is the bill of materials' structure of the different jobs entered to the shop. It contains the preliminary information about the items and their operations. This output is provided whenever a job has been completed. The second output provides a complete timetable of the different workstations in the shop. For each workstation output, the permanent date for the shop during the run will be provided, as well as the order of processing the different operations at that station, the arrival time, starting time, completion time, queueing time and idle time (if any). Samples of the outputs will be illustrated through the computerized solutions of some examples later in this chapter.

The third output will supply the total variable production costs due to the proposed schedule. Also, the total variable costs will be broken down into the various contributing variable costs (inventory costs, overtime

costs, idle time costs, and lateness costs) of each individual item. An example of the output structure is shown in Fig 4.1

4.4 Program limitations:

The program is limited to use a maximum of 9 work stations and deals with a maximum of 2 different jobs simultaneously, each of which could contain a maximum of 4 levels B.O.M.. Each job could contain a maximum of 9 operations excluding the last operation. The identification (ID) calling code of each operation consist of 4 digits:

The first digit -----> indicates job type (A or B)

The second digit ----> indicates operation's sequence # in job B.O.M. (0-9)

The third digit ----> indicates the allocated work station of the operation.

The fourth digit ----> indicates the operational period no.

N.B. The ID calling code is limited to 4 digits just to reduce the `RAM` memory size used by the program on the computer. But, in cases of having bigger ID numbers and a sufficient memory, there will be no problem to use them in the program after slight adjustments.

The above case is also applied for the following limitations:

machine hour/item	<= 9.99 hrs.
Production quantity	<= 999 units
kinds of items produced/W.S.	<= 4
Priority cost factors	<= 9.99

4.5 Example of how the model works:

The following is a simple example to demonstrate how the logic of the model works by supplying a manual solution to the problem and a computer output to the same example.

```
BILL OF MATERIALS OF ITEM #2021-3
---------------------------------

MACHINING HOURS/ITEM-------------->   .30
INVENTORY COST FACTOR/HR---------->  1.20
% AGE OF UNIT PRODUCT------------->    25
QUANTITY NEEDED------------------->    30
COMPLETE IDENTIFICATION NO.------>  2021-3
                                    ------
                                      !
                                      !
                                      !
            -----------------------------------------
             .20                                  .10
            1.20                                 1.20
              15                                   40
              30                                  120
            2121-1                               2211-1
            ------                               ------


BILL OF MATERIALS OF ITEM #1021-2
---------------------------------

MACHINING HOURS/ITEM-------------->   .20
INVENTORY COST FACTOR/HR---------->  1.20
% AGE OF UNIT PRODUCT------------->    20
QUANTITY NEEDED------------------->    40
COMPLETE IDENTIFICATION NO.------>  1021-2
                                    ------
                                      !
                                      !
                                      !
            -----------------------------------------
             .40                                  .10
            1.20                                 1.20
              35                                   45
              80                                  120
            1121-1                               1211-1
            ------                               ------
```

Fig (4.1)

```
GIVE A 3 DIGIT NAME TO WS # 1 DATA FILE: A1
W.S. DATA FILE < OLD OR NEW > : NEW

ARE INFORMATION ABOUT THE PREVIOUS RUN ON A1 .AVAILABLE ? < Y OR N

WORK STATION NORMAL SET UP TIME:0.5
WORK STATION MAXIMUM SET UP TIME:1.25
WORK STATION REGULAR TIME HOURS:8
WORK STATION MAX. O.T. HOURS:8
WORK STATION UNAVAILABILATY FACTOR:0
W.S.WORKING DAYS / WEEK :5
MAX.OPERATIONAL CAPACITY ON W.S.( <=4 ):4
O.T. COST FACTOR FOR THIS W.S.:1.5
IDLE TIME COST FACTOR/HR FOR THIS W.S.:3.0
--------------------------------------------------
CONTINUE AFTER THE OLD SCHED.?< Y / N >:N
--------------------------------------------------

ANY MORE WORK STATIONS TO ENTER?< Y OR N >:Y

GIVE A 3 DIGIT NAME TO WS # 2 DATA FILE: A2
W.S. DATA FILE < OLD OR NEW > : NEW

ARE INFORMATION ABOUT THE PREVIOUS RUN ON A2  AVAILABLE ? < Y OR N

WORK STATION NORMAL SET UP TIME:0.25
WORK STATION MAXIMUM SET UP TIME:0.75
WORK STATION REGULAR TIME HOURS:8
WORK STATION MAX. O.T. HOURS:8
WORK STATION UNAVAILABILATY FACTOR:0
W.S.WORKING DAYS / WEEK :5
MAX.OPERATIONAL CAPACITY ON W.S.( <=4 ):4
O.T. COST FACTOR FOR THIS W.S.:2.0
IDLE TIME COST FACTOR/HR FOR THIS W.S.:2.2
--------------------------------------------------
CONTINUE AFTER THE OLD SCHED.?< Y / N >:N
--------------------------------------------------

ANY MORE WORK STATIONS TO ENTER?< Y OR N >:N
```

Fig (4.2)

Given the above B.O.M. structures for products # 1021-2 & 2021-3, Fig(4.1), and data for work stations (A1) & (A2), Fig(4.2)

Show how the MCFR algorithm works to produce its final schedule for producing the above products' operations on work stations A2, A2.

Knowing that the penalty cost factor for delays from the due date/unit item is equal to:

$9.9/hr -----> for 1021-2's items

$2.0/hr -----> for 2021-3's items

A step by step solution to the above case follows:

STEP 1 Approximate due dates & (EPT) for product (job) "A" items:

*For the end item (1021):

	Year/	Month/	Day/	hour	
Due date =	5 /	12 /	19/	00	(Given)

EPT = NST + MH = 0.25 + (40 * 0.3) = 12.25 hrs.

*For item (1021)'s Predecessors:

EDD = (15/12/19/00 - (12 hrs) - 5/12/14/04

For each item according to the given working conditions.

Notice in this case that (5/12/16) & (5/12/17) are representing a two day weekend.

*For item (1121) ------> Due date = 5/12/15/04

-------> EPT = 0.25 + (0.4 * 80) = 32.25 hrs

Because (1121) is a raw material item, then:

ATM = (5/12/04)-(32 working hrs) = (5/12/11/04)

Similarly; for the other predecessors of (1021);

*For item (1211) ------> Due date = (5/12/15/04)

------> EPT = 0.5 + (120*0.1) = 13 hrs

ATM = (5/12/15/04)-(13 working hrs) =(5/12/13/07)

Repeat the same procedures to approximate the due dates of product (job) "B" items:

*For the end item (2021)----> Due date = 5/12/10/99 (given)

----> EPT = 0.25+(30*0.5) = 15.25 hrs

*For item (2021)'s Predecessors:

Due date = (5/12/19/00)-(15 w.h.) = (5/12/15/01)

For item (2121)

------> EDD = (5/12/15/01)

------> EPT = 0.25 + (30*.2) = 6.25

------> ATM = (5/12/15/01)-6 = (15/12/15/01)

For item (2211)

------> EED = 5/12/15/01

------> EPT = 0.5 +(12*0.1) = 13 w.h.

------> ATM = (5/12/15/01)-13=(5/12/13/04)

STEP 2: A more accurate estimation to the release dates of jobs A & B at workstations

By using equation (3.4):

$$(RTM_{kj})=(EDD_{kj})-((QF_j)*(EPT_{kj}))$$

For work station # 1 (j=1):

The raw materials operations W.S. # 1 are:

- Operation for item 1211 (k=1)
- Operation for item 2211 (k=2)

Using equation (3.9):

$$(ELT_{kj}) = (EDD_{kj}) - (TNOW_j)$$

As $(TNOW_j) = 0$,

$$(TNOW_j) = \min (ATM_{kj})$$

min (ATM) = min (5/12/13/07, 5/12/13/04) = 5/12/13/04

*For item (1211) operation:

(ELT_{11}) = (5/12/15/04)-(5/12/13/04) = 48 hrs.

*And for item (2211) operation:

(ELT_{21}) = (5/12/15/01) - (5/12/13/04) = 45 hrs.

So, max. (ELT_{ij}) = max (48,45) = 48 hrs.

Then, by using equations (3.8) , (3.7) & (3.6):

(T_j) = ((120*0.1) + 0.5) + ((120*0.1) + 0.5) = 25 hrs.

So, $(LPT_{jt}) = (5/12/13/04) + (25\ hrs) = 5/12/18/05$

$(APT_{jt}) = (5/12/18/05) - (5/12/13/04) = 121$ hrs.

Then by applying equation (3.5) :

$(QF_j) = (ATP_j) / \max(ELT_{ij}) = (121/48) = 2.52$

By using (3.4) the release dates of raw materials operations on station # 1 would be approximated as follows:

*For item (1211) operation:

$(RTM_{21}) = (5/12/15/04) - (2.52 * 13\ hrs) = 5/12/11/03$

*For work station # 2 (j=2):

The raw materials operations at W.S. # 2 are :-

----> Operation for item 1121 (k=1)

----> Operation for item 2121 (k=2)

Using equation (3.9):

$(ELT_{kj}) = (EDD_{kj}) - (TNOW_j)$

$(TNOW_j) = 0.$ Then,

$(TNOW_j) = \min(ATM_{kj}) = \min(5/12/11/04,\ 5/12/14/03) = 5/12/11/04$

For item (1121) operation:

$(ELT_{12}) = (5/12/15/04 - (5/12/11/04) = 96$ hrs

For item 2121 operation:

$(ELT_{22}) = (5/12/15/01) - (5/12/11/04) = 93$ hrs

Max (ELT_{ij}) max = (96, 93) = 96 hours ------------->

Then by using equations (3.8) , (3.7) & (3.6)

$(T_j) = ((80*0.4) + 0.25) + ((30*0.2) + 0.25) = 39$ hrs.

So, $(LPT_{jt}) = (5/12/11/04) + 39 = 5/12/18/03$

$(APT\ \ ) = (5/12/18/03) - (5/12/11/04) = 167$ hours.

Then by applying equation (3.5):

$(QF_j) = (APT_j) / \max (ELT_{ij}) = (167/96) = 1.74$

By using (3.4); the release dates of raw materials operations operations on station #2 would be approximated as follows:

For item (1121) operation:

$(RTM_{12}) = (5/12/15/14) - (1.74*6+0.5) = 5/12/06/04$

For item (2121) operation:

$(RTM_{22}) = (5/12/15/14) - (1.74*6+0.5) = 5/12/13/07$

Then, moving to step (3) to select the best candidate operation to process at each work station among the (R) operations according to the (MCFR) rule.

For Work Station #1:

There are two raw materials (R) operations on this station:

1- Operation for item 1211

2- Operation for item 2211

(A1) Starting With Item 1211 Operation as operation #1:

Using the regular time bases:

$(TNOW_1) = (ATM_{11}) = 5/12/11/03$

$(QTM_{11}) = (TNOW_1) - (ATM_{11}) = 0$

$(QCOST_{11}) = (QTM_{11}*COP_{11}*IQTY_{11}*ICF_{1211})/100 = 0$ ---> 1

$(IDLET_{11}) = 0$

$(IDCOST_{11}) = (IDLET_{11}*IDCF_1) = 0$

$(CTM_{11}) = (TNOW_1)+(EPT_{11}) = (5/12/11/03)+13 = 5/12/13/00$

$(IDD_{11}) = (5/12/15/04)$

$(ETIME_{11}) = (5/12/15/04) - (5/12/13/00) = 52$ hrs.

$(HCOST_{11}) = (52*1.5*120*45) / 100 = \$ 4212$ ---------> *

$(HTCOST_{11}) = 0$; because the twin operation (1121) has not been completed yet.

$(DCOST_{11}) = 0$; because CTM < IDD

Then, (PVC) = 0 + 0 4212 + 0 + 0 +0 = \$ 4212 -----> *

Also, because (Dcost) = 0, working overtime hours for this operation will not be needed.

So, $(PVC_{11})' = (PVC_{11}) = \$ 4212$

Now, adjust work station # 1 clock temporarily:

i.e. $TNOW_1 = CTM_{11} = 5/12/13/00$

(A2) Processing item (2211) operation as operation # 2: Using the regular time bases

$(TNOW_1) = 5/12/13/00$ & $(ATM_{21}) = 5/12/11/00$

$(ATM_{21}) = (TNOW)-(ATM) = (5/12/12/00)-(5/12/11/00)$

$(QTM21) = (TNOW)-(ATM) = (5/12/13/00)-(5/12/11/00) = 48$ hrs

$(QCOST_{21}) = (QTM_{21} * COP_{21} * IQTY_{21} * ICF_{21}) / 100$

$= (48 * 60 * 120 * 2) / 100 = \$ 6912.00$

$(IDCOST21) = 0$

As LJN = JN, then; ST = 0 & EPT = (120*0.1) + ST = 12 hrs.

$(CTM_{21}) = (5/12/13/00) + (12) = 5/12/14/04$

$(IDD_{21}) = (5/12/15/01)$

$(ETIME_{21}) = (5/12/15/04)-(5/12/13/00) = 20$ hrs.

$(LTIME_{21}) = 0$; because CTM < IDD

$(HCOST_{21}) = (ETIME * 120 * 60 * 0.3)/100 = \$3024$ ----> *

HTCOST = 0; because the twin operation (2121) has not been completed yet.

$(DCOST_{21}) - (LTIME_{21} * COP_{21} * IQTY_{21} * DCOST_{21})/100 = 0$

Then, $(PVC_{21}) = 6912 + 3024 = \$9936$ ---------------> *

Also, working overtime hours for this operation will not be needed.

So, $(PVC_{21})' = (PVC_{21}) = \$ 9936$

And, $(TPVC_{21}) = (PVC_{11}) + (PVC_{21}) = 4212 + 9936 = \$ 14,148$

(B1) Starting with item (2211) operation as operation # 1: Using regular time basis

$(TNOW_1) = (ATM_{11}) = 5/12/11/00$

$(QTM_{11}) = (TNOW_1) - (ATM_{11}) = 0$

$(QCOST_{11}) = 0$

$(IDCOST_{11}) = 0$

$(EPT_{11}) = 12 + 0.5 = 13$ hrs where $(ST_{11} = 0.5)$

$(CTM_{11}) = (5/12/11/00) + (13) = 5/12/12/05$

$(IDD_{11}) = (5/12/15/01)$

$(ETIME_{11}) = (IDD_{11}) - (CTM_{11}) = 68$ hrs.

$(HCOST_{11}) = (68 * 120 * 60 * 2.0)/100 = 9792$

$(LTIME_{11}) = 0$

$(DCOST_{11}) = 0$

HTCOST = 0

(PVC) = \$9792

Also, working overtime hours for this operation will not be needed.

So, $(PVC_{11}) = (PVC_{11})' = \$9792$

Then, adjust work station # 1 clock temporarily

i.e., $TNOW_1 = CTM_{21} = 5/12/12/05$

<u>(B2) Processing item (1211) operation as operation # 2: Using the regular time bases</u>

$(TNOW_1) = 5/12/12/05$

$(ATM_{21}) = 5/12/11/03$

$(QTM_{21}) = (TNOW_1) - (ATM_{21}) = 26$ hrs.

(QCOST) = 26 * 120 * 1.5 * 45)/100 = \$ 2106

LJN = JN = 1; So, ST = 0 ; MT = 12 ; EPT = MT + ST = 12

$IDCOST_{21} = 0$

$(CTM_{21}) = (TNOW_1) + (EPT_{21}) = 5/12/14/01$

$(IDD_{21}) = 5/12/15/04$

$(ETIME_{21}) = CTM_{21} - IDD_{21} = 27$ hrs.

$(ECOST_{21}) = (27 * 120 * 1.5 * 4.5)/100 = \$ 2187$

$(DCOST_{21}) = 0$

$(HTCOST_{21}) = 0$

$(PVC_{21}) = 2187 + 2106 = \$4293$

As DCOST = 0, working overtime hours for this operation will not be needed.

So $(TPVC_{21}) = (PVC_{11}) + (PVC_{21}) = 4293 + 9792 = \$14085$

$(TPVC)*1 = \min (TPVC_{11} , TPVC_{21}) = \$14085$ ------> *

Then, operation of the item (2211) will be processed first at station # 1 according to the (MCFR) -------> *

<u>For Work Station # 2</u>

<u>There are two raw material operations at this work station:</u>

1- Operation for item (1121)

2- Operation for item (2121)

Starting with item 1211 operation as operation #1

Using regular time bases:

$(TNOW_2) = (ATM_{12}) = 5/12/06/04$

$(QTM_{12}) = 0$; $(QCOST_{12}) = 0$

$(IDLET_{12}) = 0$; $(IDCOST_{12}) = 0$

ST = 0.25 ; EPT = 32 hrs

$(CTM_{12}) = (5/12/06/04) + 32 = 5/12/12/04$

$(IDD_{12}) = 5/12/15/04$; $(ETIME_{12}) = 72$ hrs

$(HCOST_{12}) = (72*80*1.2*35)/100 = \$2419.2$

$(HTCOST_{12}) = 0$; $(DCOST_{12}) = 0$

$(PVC_{12}) = \$\ 2419.2$

And, working overtime hours for this operation will not be needed.

So, $(PVC_{12}) = (PVC_{12})'$

Then, adjust work station # 2 clock temporarily

i.e. $(TNOW_2) = (CTM_{12}) = 5/12/12/04$

(A2) Processing item (2121) operation (as operation # 2 Using the regular time bases

$(TNOW_2) = 5/12/12/04$

$(ATM_{22}) = 5/12/13/07$

(ATM > TNOW). Then, $(TNOW_2) = (ATM_{22}) = 5/12/13/07$

$(IDLET_{22}) = (TNOW_2) - (ATM_{22}) = 11$ hrs.

$(IDCOST_{22}) = (IDLET_{22}) * (IDCF_2) = 11 * 2.2 = \$24.2$

$(QTIME_{22}) = 0$; $(QCOST_{22}) = 0$

$(CTM_{22}) = (5/12/13/07) + 6$ hrs $= 5/12/14/05$

$(IDD_{22}) = (5/12/15/01)$

$(ETIME_{22}) = (CTM_{22}) - (IDD_{22}) = 20$ hrs. ------> *

$(HCOST_{22}) = (20*30*75*1.0) / 100 = \$\ 450$ ------> *

$(ITWIN_{22})$ = is 2211 ; $(CTMT_{22}) = 5/12/14/05$

$(CTM_{22}) = 5/12/13/07$

DIFF $= (CTM_{22}) - (CTMT_{22}) = 48$ hrs.

HTCOST $= (48 * 2 * 60 * 120) / 100 = \$6912$ ----> *

DCOST = 0; i.e. No need for using the overtime basis.

And, $(PVC_{22}) = 6912 + 24.2 + 450 = \$ 7386.2$ ---> *
Then, $(TPVC_{12})=(PVC_{11}) + (PVC_{22})=7385.2 + 2419.2 =$
$\$ 9805.4$

<u>(B1) Starting with item (2121) operation as operation # 1 Using regular time basis</u>

$(TNOW_2) = (ATM_{12}) = 5/12/13/07$
$(QTM_{12}) = 0$; $(EDLET_{12}) = 0$
$(QCOST_{12}) = 0$; $(IDCOST_{12}) = 0$
$(CTM_{12}) = (TNOW_2) + (EPT_1) = 5/12/14/05$
$(IDD_{12}) = 5/12/15/01$
$(ETIME_{12}) = 5/12/15/01$
$(HCOST_{12}) = (20*30*(60+15)*1.0)/100 = \$ 450$
$(FTMT_{12}) = 5/12/12/05$ 1 *FTM12) = 5/12/14/05
DIFF = (FTM) - (FTMT) = 48 hrs.
$(HCOST_{12}) = 48 * 120 * 60 * 2.0 = \$ 6912$ --------> *
(DCOST) = 0; So overtime hours will not be needed.
And $(PVC_{12}) = 6912 + 450 = \$ 7362$ -----------> *
$(PVC_{12})' = (PVC_{12}) = \$7362$
Then, adjust work station #2 clock temporarily,
<u>i.e.</u> $(TNOW_2) = (CTM_{12}) = 5/12/14/05$

<u>(B2) Processing item (1121) operation (as operation # 2: Using regular time hours</u>

$(TNOW_2) = 5/12/14/05$
$(ATM_{22}) = 5/12/06/04$
$(QTIME_{22}) = (TNOW_2) - (ATM_{22}) = 193$ hrs.
$(QCOST_{22}) = (193*80*35*1.2)/100 = \$ 6484.8$ ---> *
$(IDLET_{22}) = 0$; $(IDCOST_{22}) = 0$
$(CTM_{22}) = (TNOW_2) + (EPT_{22}) = 5/12/20/05$
$(IDD_{22}) = 5/12/15/04$
$(LTIME_{22}) = (IDD_{22}) - (CTM_{22}) = 121$ hrs.
$(DCOST_{22}) = (121*80*35*9.9)/100 = \$ 33541.2$ ---> *

$(ETIME) = 0$; $(HCOST) = 0$; $(HTCOST) = 0$

$(PVC_{22}) = 33541.2 + 6484.8 = \$\ 40026$ ---------> *

Due to the 121 hrs. delay from the due date the overtime options should be tried.

(TNOW) will be the same as in the regular time bases because there was no indication of using the overtime bases in the previous run, but if so, then TNOW should be adjusted such that both overtime periods should be joined together. Then, $(TNOW_2) = 5/12/14/05$; $(ATM_{22}) = 5/12/06/04$; $IDCOST_{22} = 0$

$(QCOST_{22})' = \$\ 6484.8$

$(CTM_{22})' = (TNOW_2) + (EPT_{22}) = 5/12/18/05$

$(IDD22)' = 5/12/15/04$

$(LTIME_{22})' = (IDD_{22}) - (CTM_{22}) = 73$ hrs.

$(DCOST_{22})' = (73*80*35*9.9)/100 = \$\ 20235.6$

$(OTCOST_{22}) = 100[(CTM_{22}) - (CTM_{22})'] * OTPC$

$= 100 * 16 * 2.0 = \$\ 3200$

And, $(PVC_{22})' = 3200 + 202035.6 + 6448.8 = \$29920.4$

As $(PVC_{22})' < (PVC_{22})$, then the overtime bases will be used for this operation.

$(TPVC_{22}) = (PVC_{12}) + (PVC_{22})' = 7362 + 29920.4$

Then $(TPVC)*2 = \text{Min}\ (TPVC_{12}\ ,\ TPVC_{22})$

$= \text{Min}\ (9805.4,\ 37282.4) = 9805.4$

i.e. Item (1121)'s operation should be processed first at work station # 2 according to the (MCFR) rule.

Next at work station # 1 there will be only one job and it will be processed automatically, unless new job(s) would be introduced before the completion time of the existing job in process at that work station.

And for work station # 2 there will be 2 operations ready for processing (items 2121 & 1021 operations).

They will be in competition under the same (MCFR) rule. When a finished item is produced the model is ready to accept a new product to enter and its jobs will compete with existing (remaining) jobs. If there are no new jobs, those remaining jobs will be processed alone but also under the (MCFR) rule. The model will reach it's end only if there are no jobs existing in it (which is the case in our example). A complete solution of this example problem will be shown in a computerized output in the following section.

Next a summary and conclusions to the predescribed approach are given, provided with some recommendations for further research under the same concept.

```
DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
-----------------------------------------------------------
(4)    ITEM'S ID #:1211
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:3
(6)    ITEM'S TWIN ID #    (IF ANY):1121
(7)    ITEM'S CHILD ID #   (IF ANY):0
(8)    ITEM'S PARENT ID # (IF ANY):1021
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :45
(10)   INVENTORY COST FACTOR /UNIT ITEM :1.5
(11)   MACHINING TIME / UNIT (HRS.) :0.1
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:1
-----------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
-----------------------------------------------------------
(4)    ITEM'S ID #:1021
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:1
(6)    ITEM'S TWIN ID #    (IF ANY):0
(7)    ITEM'S CHILD ID #   (IF ANY):1121
       MORE CHILDREN TO ENTER ? :Y
(7)    ITEM'S CHILD ID #   (IF ANY):1211
(8)    ITEM'S PARENT ID # (IF ANY):0
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :20
(10)   INVENTORY COST FACTOR /UNIT ITEM :2.5
(11)   MACHINING TIME / UNIT (HRS.) :0.3
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:2
-----------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:N
-----------------------------------------------------------


 ADJUSTING THE LAST PRODUCT'S ITEMS D.DATE ...FIRST !!
***********************************************************

 ENTER THE PRODUCTS DUE DATE : 5121900
***********************************************************
(1)    PRODUCT A OR B ?:B
(2)    DELAY FROM D. DATE PENALTY FACTOR <#.##>:2.0
(3)    QUANTITY NEEDED :30
(4)    ITEM'S ID #:2121
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:1
(6)    ITEM'S TWIN ID #    (IF ANY):2211
(7)    ITEM'S CHILD ID #   (IF ANY):0
(8)    ITEM'S PARENT ID # (IF ANY):2021
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :15
(10)   INVENTORY COST FACTOR /UNIT ITEM :1.0
(11)   MACHINING TIME / UNIT (HRS.) :0.2
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:1
-----------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N
```

```
DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
------------------------------------------------------------
(4)    ITEM'S ID #:2211
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:4
(6)    ITEM'S TWIN ID #    (IF ANY):2121
(7)    ITEM'S CHILD ID #   (IF ANY):0
(8)    ITEM'S PARENT ID # (IF ANY):2021
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :60
(10)   INVENTORY COST FACTOR /UNIT ITEM :2.0
(11)   MACHINING TIME / UNIT (HRS.) :0.1
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:1
------------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
------------------------------------------------------------
(4)    ITEM'S ID #:2021
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:1
(6)    ITEM'S TWIN ID #    (IF ANY):0
(7)    ITEM'S CHILD ID #   (IF ANY):2121
       MORE CHILDREN TO ENTER ? :Y
(7)    ITEM'S CHILD ID #   (IF ANY):2211
(8)    ITEM'S PARENT ID # (IF ANY):0
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :25
(10)   INVENTORY COST FACTOR /UNIT ITEM :1.5
(11)   MACHINING TIME / UNIT (HRS.) :0.5
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:3
------------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:N

 ENTER THE PRODUCTS DUE DATE : 5121900


 IS THE BILL OF MATERIAL STRUCTURE REQUIRED ? < Y OR N >Y
```

WORKSTATION # 1 DATA

SET UP TIME HRS. NORMAL	SET UP TIME HRS. MAXIMUM	R.TIME HOURS	O.TIME HOURS	WORKING DAYS/WEEK	UNAVAL-ABILITY FRACTION	COST FACTORS IDLE T.	COST FACTORS OVER T.
.50	1.25	8	8	5	.00	3.00	1.50

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
2211	120	12/11/ 0	12/11/ 0	12/12/ 5	REGULAR	0	0
1211	120	12/12/ 5	12/12/ 5	12/14/ 1	REGULAR	0	0

MIN. TOTAL VARIABLE COSTS:

USING THE MCFR. RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
2211	2106	0	11979	0	0	0	14085
1211	3744	1512	3888	0	0	0	9144

TOT.MIN.V. COSTS = $ 23229

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE THE MINIMUM POSSIBLE V. COST OF THE WHOLE ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 2 DATA

SET UP TIME HRS.		R.TIME	O.TIME	WORKING	UNAVAL-ABILITY	COST FACTORS	
NORMAL	MAXIMUM	HOURS	HOURS	DAYS/WEEK	FRACTION	IDLE T.	OVER T.
.25	.75	8	8	5	.00	2.20	2.00

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
1121	80	12/ 6/ 4	12/ 6/ 4	12/12/ 4	REGULAR	0	0
2121	30	12/12/ 4	12/12/ 4	12/13/ 2	REGULAR	0	0
2021	30	12/13/ 2	12/13/ 2	12/15/ 2	REGULAR	0	0
1021	40	12/14/ 1	12/15/ 2	12/18/ 6	REGULAR	25	0

MIN. TOTAL VARIABLE COSTS:

USING THE MCFR. RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
1121	0	6912	2869	0	24	0	9805
2121	0	6912	3150	0	24	0	10086
2021	2500	0	6030	0	0	0	8530
1021	2500	0	1800	0	0	0	4300

TOT.MIN.V. COSTS = $ 32721

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE THE MINIMUM POSSIBLE V. COST OF THE WHOLE ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM IS CHOSEN TO BE PROCESSED FIRST ON STATION

CHAPTER V

SUMMARY AND RECOMMENDATION

The proposed heuristic-algorithm to multi-level production scheduling in FMS has been discussed. This algorithm utilizes features of the variable lead time and set-up time, and attempts to minimize the total costs as a major objective.

Set - up time costs, overtime costs, inventory costs and penalties for the lateness and machine idle time are considered as the major cost factors that govern the output schedule.

Some existing popular methods are compared with this computer based heuristic algorithm. These methods are First In First Out (FIFO), Shortest Processing Time (SPT) and Longest Processing Time (LPT). In FIFO, the oldest item at the work station is processed first. Over a wide range of assumptions, this method reduces the inventory and minimizes the job flow. SPT allows the job with the smallest time to begin first at the work station. SPT minimizes the average job flow time by minimizing both the average job waiting and lateness times. In the LPT method, which is the opposite of the SPT method, the job with the longest time begins first at the work station. Its main advantages are to reduce inventory and to have a better machine utilization. In the above three methods, the emphasis is focused on certain criteria as a major objective, rather than considering all the different criteria that affect the PSS in the FMS environment (which is the case in the proposed algorithm).

Comparison of the three methods with the proposed one is done for the typical production conditions listed in appendix A.

The output results of the proposed algorithm showed a lower total variable costs against the FIFO, SPT and LPT methods as summarized below.

For Work Station # 1

Min. Total Variable Costs ($)

Sample #	MCFR	FIFO	LPT	SPT
1	23229	23292	42596	26568
2	6926	16948	16948	16783
3	86155	208449	244545	230566

For Work Station # 2

Min. Total Variable Costs ($)

Sample #	MCFR	FIFO	LPT	SPT
1	32721	48200	39564	192106
2	20601	29080	31695	186805
3	123451	144417	305945	844644

Intuitively, as a result of considering all possible different scheduling alternatives with the above cost factors simultaneously, the proposed algorithm (MCFR) should give lower total variable costs than the other methods.

In summary, although the theoretically based optimizing procedure for the multi-level PSS problem in an FMS environment might be of interest from a research stand point, it has little practical, (as well as unobtainable at current states of the art) use in industry. Therefore, the search for practical method for solving multi-level PSS problem is clearly warranted. The proposed algorithm gives fairly good approximations to optimal solutions with large computational requirements. Therefore, this algorithm could be a very useful tool to handle the multi-level PSS problems in the FMS environment in some industries.
These industries are the ones that need to consider minimizing the total costs as main production criteria.

Based on the proposed method, the following are the possible extensions to this research:

(1) Releasing some of the existing assumptions in the algorithm (such as storage limitations and the max levels of B.O.M.), and using stochastic instead of deterministic applications to approach the exact real life situation.

(2) Using optimization approach (such as goal programming) rather than the heuristics.

(3) Using computer simulation and/or artificial intelligence techniques in the model for more analysis of the different factors and the behavior of the model.

(4) Considering labor costs in more detail, and optimizing the labor force at each work station.

REFERENCES

1. Baker, Kenneth R. and Kanet, John J. "Improved Decisions Rules In Combined Systems For Minimizing Job Tardiness, "International Journal Of Production Research, Vol. 22, Nov 1984.

2. Baker, Kenneth R., Introduction To Sequencing And Scheduling, John Wiley, New York, 1974.

3. Berry, W.L. and V. Rac, "Critical Ratio Scheduling: An Experimental Analysis" Management Science, Vol. 22, No. 2, 1975.

4. Bertrand, J.W.M. "The Effect Workload Dependent Due Dates On Job Shop Performance," The Institute of Management Science, 1983.

5. Buffa, E.S. and J.G. Miller, Production Inventory Systems Planning And Control, Third Ed, Richard D. Irwin, Homewood, Illinois, 1979.

6. Bullers, Williams I., Shimon Y. Nof and Whinston. Andrew B., "Artificial Intelligence In Manufacturing Planning And Control," AIIE Transaction Dec 1980.

7. Buzacott, J.A. and Shanthikumar, J.G., "Models For Understanding Flexible Manufacturing System," AIIE Transaction, December, 1980.

8. Conway, R.W., Maxwell, W.L. and Miller, L.W.; "Theory of Scheduling," Addison-Wesley. Massachusetts, 196[illegible].

9. Davis, Robert., Tanchoco, J.M.A., Agee, Marivn H. and Wysk, Richard A., "Manufacturing Systems Planning-The Key To Production Control," IIE Proceedings, 1979

10. Day, J.E. and Hottenstein, M.P., "Review of Sequencing Research" Naval Research Logistics Quarterly, Vol. 17, March 1970.

11. Fazle Rabbi, and Park, Eui H., "Development of an Integrated Planning and Control Model for Discrete Production Systems", Working paper, North Carolina A&T State University 1984.

12. Fox, Mark S. and Smith, Stephen F.,"ISIS Acknowledge Based System for Factory Scheduling," Expert System Journal, Vol. 1, No.1, July 1984.

13. Green, I. Gary and Leonard, Appel B. "An Enpirical Analysis of Job Dispatch Rule Selection:, Journal of Operations Management, APICS, May 1981.

14. Greene, Timothy J. and Sadowski, Rondall P.,"Loading The Cellularly Divided Group Technology Manufacturing System," IE conference Proceeding Fall 1980.

15. Groover, Mikell P. and Zimmers, Emory W. Jr., "CAD/CAM: Computer Aided Design and Manufacturing," Orebtuce Gakkm Inc, 1984.

16. Kimemia, Joseph & Stanley B. Gershwin, "Flow Optimization In Flexible Manufacturing Systems," International Journal of Production Research Vol. 23, No. 1, 1985.

17. Kiran, Ali S. and Tansel, Barboros C., "A Framework For Flexible Manufacturing System," AIIE Conference Proceeding, 1985.

18. Mize, J.H., White, C.R. and Brooks, G.H., "Operations Planning and Control," Englewood Cliffs, New Jersery: Prentice - Hall, Inc., 1977.

19. Miyazaki, S., "Combined Scheduling Sytem for Reducing Job Tradiness in a Job Shop," International Journal of Production Research, Vol. 19, 1981.

20. Moore, Ted L., "Information Systems for Closed Loop Production Control Systems," AIIE Conference Proceeding 1984.

21. Moore, Ted L., "Intermediate Stocks in MRP Systems," AIIE Conference Proceeding 1985.

22. Nof, S.Y., Barash, M.M. and Solberg, J.J., "Operation Control of Item Flow in Versatile Manufacturing Systems," International Journal of Production Research, Vol. 17, 1979.

23 Panwalker, S.S. and Iskander W., "A Survey of Scheduling Rules," Operation Research, Vol. 25 No. 1

24. Ragatz, Gary L. and Mabert, Vincent A.,"A Framework For The Study OF Due Date Management In Job Shops," International Journal Production Research 1984. Vol. 22, No. 4, 685-695.

25. Sarin, S.C. and Dar El, E.M. ,"Approach To The Scheduling Problem In FMS", IIE Fall 1984 IIE Conference Proceeding.

26. Stecke, Kathry, E. and Solberg, James J., "Loading and Control Policies For A Flexible Manufacturing System", International Journal Production Research, 1981 Vol. 19, No. 5 581-490.

27. Swan, Don M., "Planning And Inventory Control in Low Volume Environments," AIIE Conference Proceedings, 1985.

28. Truscott, Williams G., "Scheduling Production Activirties In Multi-Stage Batch Manufacturing Systems," International Journal Production Research, 1985 Vol. 23 No.2, 315-328.

29. Zmolek, Dennis F., "Reduced Cost Through Group Technology Application," IIE Conference Proceedings, Fall, 1984.

APPENDIX A

Computerized Input, Outputs and Solutions to to a modified example using MCFR, LPT, SPT & FIFO

```
 EX SABER.FOR
LINK:   Loading
[LNKXCT SABER execution]

 GIVE A 3 DIGIT NAME TO WS # 1 DATA FILE: B1
 W.S. DATA FILE < OLD OR NEW > : NEW

 ARE INFORMATION ABOUT THE PREVIOUS RUN ON B1  AVAILABLE ? < Y OR N > :N

 WORK STATION NORMAL SET UP TIME:0.5
 WORK STATION MAXIMUM SET UP TIME:1025
 WORK STATION REGULAR TIME HOURS:8
 WORK STATION MAX. O.T. HOURS:8
 WORK STATION UNAVAILABILATY FACTOR:0
 W.S.WORKING DAYS / WEEK :5
 MAX.OPERATIONAL CAPACITY ON W.S.( <=4 ):4
 O.T. COST FACTOR FOR THIS W.S.:1.5
 IDLE TIME COST FACTOR/HR FOR THIS W.S.:3.0
-------------------------------------------------------
CONTINUE AFTER THE OLD SCHED.?< Y / N >:N
-------------------------------------------------------

ANY MORE WORK STATIONS TO ENTER?< Y OR N >:Y


 GIVE A 3 DIGIT NAME TO WS # 2 DATA FILE: B2
 W.S. DATA FILE < OLD OR NEW > : NEW

 ARE INFORMATION ABOUT THE PREVIOUS RUN ON B2  AVAILABLE ? < Y OR N > :N

 WORK STATION NORMAL SET UP TIME:0.25
 WORK STATION MAXIMUM SET UP TIME:0.75
 WORK STATION REGULAR TIME HOURS:8
 WORK STATION MAX. O.T. HOURS:8
 WORK STATION UNAVAILABILATY FACTOR:0
 W.S.WORKING DAYS / WEEK :5
 MAX.OPERATIONAL CAPACITY ON W.S.( <=4 ):4
 O.T. COST FACTOR FOR THIS W.S.:2
 IDLE TIME COST FACTOR/HR FOR THIS W.S.:20
-------------------------------------------------------
CONTINUE AFTER THE OLD SCHED.?< Y / N >:N
-------------------------------------------------------

ANY MORE WORK STATIONS TO ENTER?< Y OR N >:N
*********************************************************
GIVE A 3 DIGIT NAME TO ITEMS DATA FILE:B12
ITEMS DATA FILE < OLD OR NEW >:NEW
*********************************************************
(1)    PRODUCT A OR B ?:A
(2)    DELAY FROM D. DATE PENALTY FACTOR <#.##>:9.9
(3)    QUANTITY NEEDED :40
(4)    ITEM'S ID #:1121
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:2
(6)    ITEM'S TWIN ID #    (IF ANY):1211
(7)    ITEM'S CHILD ID #   (IF ANY):0
(8)    ITEM'S PARENT ID # (IF ANY):1021
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :35
(10)   INVENTORY COST FACTOR /UNIT ITEM :1.2
(11)   MACHINING TIME / UNIT (HRS.) :0.4
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:1
-------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N
```

```
DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
------------------------------------------------------------
(4)     ITEM'S ID #:1211
(5)     HOW MANY ITEMS /UNIT PRODUCT ?:3
(6)     ITEM'S TWIN ID #    (IF ANY):1121
(7)     ITEM'S CHILD ID #   (IF ANY):0
(8)     ITEM'S PARENT ID # (IF ANY):1021
(9)     ITEM'S % AGE W.R.T. UNIT PRODUCT :45
(10)    INVENTORY COST FACTOR /UNIT ITEM :1.2
(11)    MACHINING TIME / UNIT (HRS.) :.1
(12)    ITEM'S JOB NATURE CODE < 1,2 OR 3 >:1
------------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
------------------------------------------------------------
(4)     ITEM'S ID #:1021
(5)     HOW MANY ITEMS /UNIT PRODUCT ?:1
(6)     ITEM'S TWIN ID #    (IF ANY):0
(7)     ITEM'S CHILD ID #   (IF ANY):1121
        MORE CHILDREN TO ENTER ? :Y
(7)     ITEM'S CHILD ID #   (IF ANY):1211
(8)     ITEM'S PARENT ID # (IF ANY):0
(9)     ITEM'S % AGE W.R.T. UNIT PRODUCT :20
(10)    INVENTORY COST FACTOR /UNIT ITEM :1.2
(11)    MACHINING TIME / UNIT (HRS.) :0.3
(12)    ITEM'S JOB NATURE CODE < 1,2 OR 3 >:2
------------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:N
------------------------------------------------------------


 ADJUSTING THE LAST PRODUCT'S ITEMS D.DATE ...FIRST !!
************************************************************

 ENTER THE PRODUCTS DUE DATE : 5121900
************************************************************
(1)     PRODUCT A OR B ?:B
(2)     DELAY FROM D. DATE PENALTY FACTOR <#.##>:200
(3)     QUANTITY NEEDED :30
(4)     ITEM'S ID #:2121
(5)     HOW MANY ITEMS /UNIT PRODUCT ?:1
(6)     ITEM'S TWIN ID #    (IF ANY):2211
(7)     ITEM'S CHILD ID #   (IF ANY):0
(8)     ITEM'S PARENT ID # (IF ANY):2021
(9)     ITEM'S % AGE W.R.T. UNIT PRODUCT :15
(10)    INVENTORY COST FACTOR /UNIT ITEM :1.2
(11)    MACHINING TIME / UNIT (HRS.) :022
(12)    ITEM'S JOB NATURE CODE < 1,2 OR 3 >:1
------------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
------------------------------------------------------------
```

```
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:4
(6)    ITEM'S TWIN ID #    (IF ANY):2121
(7)    ITEM'S CHILD ID #   (IF ANY):0
(8)    ITEM'S PARENT ID # (IF ANY):2021
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :60
(10)   INVENTORY COST FACTOR /UNIT ITEM :1.2
(11)   MACHINING TIME / UNIT (HRS.) :0.1
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:1
-------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:Y
IS THE NEXT ITEM FROM THE SAME PREVIOUS PRODUCT?< Y OR N >:Y
-------------------------------------------------------
(4)    ITEM'S ID #:2021
(5)    HOW MANY ITEMS /UNIT PRODUCT ?:1
(6)    ITEM'S TWIN ID #    (IF ANY):0
(7)    ITEM'S CHILD ID #   (IF ANY):2121
       MORE CHILDREN TO ENTER ? :Y
(7)    ITEM'S CHILD ID #   (IF ANY):2211
(8)    ITEM'S PARENT ID # (IF ANY):0
(9)    ITEM'S % AGE W.R.T. UNIT PRODUCT :25
(10)   INVENTORY COST FACTOR /UNIT ITEM :1.2
(11)   MACHINING TIME / UNIT (HRS.) :0.5
(12)   ITEM'S JOB NATURE CODE < 1,2 OR 3 >:3
-------------------------------------------------------
DO THE ABOVE VARIABLES NEED ANY CHANGES ? < Y OR N > :N

DO YOU HAVE MORE ITEMS TO ENTER ? <Y OR N>:N

 ENTER THE PRODUCTS DUE DATE : 5121900


 IS THE BILL OF MATERIAL STRUCTURE REQUIRED ? < Y OR N >Y
```

```
                   BILL OF MATERIALS OF ITEM #2021-3
                   ---------------------------------


MACHINING HOURS/ITEM---------->   .50
INVENTORY COST FACTOR/HR------>  1.20
% AGE OF UNIT PRODUCT--------->    25
QUANTITY NEEDED--------------->    30
COMPLETE IDENTIFICATION NO.---> 2021-3
                                ------
                                  !
                                  !
                                  !
              ------------------------------------
               .20                                 .10
              1.20                                1.20
                15                                  60
                30                                 120
              2121-1                             2211-1
              ------                             ------
MORE DEMANDS TO SCHEDULE ? < Y OR N >:N
```

```
                   BILL OF MATERIALS OF ITEM #1021-2
                   ---------------------------------


MACHINING HOURS/ITEM---------->   .30
INVENTORY COST FACTOR/HR------>  1.20
% AGE OF UNIT PRODUCT--------->    20
QUANTITY NEEDED--------------->    40
COMPLETE IDENTIFICATION NO.---> 1021-2
                                ------
                                  !
                                  !
                                  !
              ------------------------------------
               .40                                 .10
              1.20                                1.20
                35                                  45
                80                                 120
              1121-1                             1211-1
              ------                             ------
MORE DEMANDS TO SCHEDULE ? < Y OR N >:N
```

WORKSTATION # 1 DATA

SET UP TIME HRS. NORMAL	MAXIMUM	R.TIME HOURS	O.TIME HOURS	WORKING DAYS/WEEK	UNAVAL-ABILITY FRACTION	COST FACTORS IDLE T.	OVER T.
.50	1.25	8	L	5	.00	3.00	1.50

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
2211	120	12/11/ 0	12/11/ 0	12/12/ 5	REGULAR	0	0
1211	120	12/12/ 5	12/12/ 5	12/14/ 1	REGULAR	0	0

MIN. TOTAL VARIABLE COSTS:

USING THE MCFR. RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
2211	1684	0	7624	0	0	0	9309
1211	2995	1512	3110	0	0	0	7617

TOT.MIN.V. COSTS = $ 16926

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE
THE MINIMUM POSSIBLE V. COST OF THE WHOLE
ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM
IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 2 DATA

SET UP TIME HRS. NORMAL	MAXIMUM	R.TIME HOURS	O.TIME HOURS	WORKING DAYS/WEEK	UNAVAL-ABILITY FRACTION	COST FACTORS IDLE T.	OVER T.
.25	.75	8	8	5	.00	0.00	0.02

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T HRS
1121	80	12/ 6/ 4	12/ 6/ 4	12/12/ 4	REGULAR	0	0
2121	30	12/12/ 4	12/12/ 4	12/13/ 2	REGULAR	0	0
2021	30	12/13/ 2	12/13/ 2	12/15/ 2	REGULAR	0	0
1021	40	12/14/ 1	12/15/ 2	12/18/ 6	REGULAR	25	0

MIN. TOTAL VARIABLE COSTS:

USING THE MCFR. RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
1121	0	4147	2959	0	0	0	7106
2121	192	4147	1644	0	0	0	5983
2021	1200	0	4248	0	0	0	5448
1021	1200	0	864	0	0	0	2064

TOT.MIN.V. COSTS = $ 20601

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE THE MINIMUM POSSIBLE V. COST OF THE WHOLE ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 1 DATA

SET UP TIME HRS.		R.TIME	O.TIME	WORKING	UNAVAL-ABILITY	COST FACTORS	
NORMAL	MAXIMUM	HOURS	HOURS	DAYS/WEEK	FRACTION	IDLE T.	OVER T.
.50	1.25	8	8	5	.00	3.00	1.50

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
2211	120	12/11/ 0	12/11/ 0	12/12/ 5	REGULAR	0	0
1211	120	12/12/ 5	12/12/ 5	12/14/ 1	REGULAR	0	0

MIN. TOTAL VARIABLE COSTS:

USING THE LPTM RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
2211	4147	0	5184	0	0	0	9331
1211	2995	1512	3110	0	0	0	7617

TOT.MIN.V. COSTS = $ 16948

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE
THE MINIMUM POSSIBLE V. COST OF THE WHOLE
ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM
IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 2 DATA

SET UP TIME HRS. NORMAL	MAXIMUM	R.TIME HOURS	O.TIME HOURS	WORKING DAYS/WEEK	UNAVAIL-ABILITY FRACTION	COST FACTORS IDLE T.	OVER T.
.25	.75	8	8	5	.00	2.20	2.00

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
1121	80	12/ 6/ 4	12/ 6/ 4	12/12/ 4	REGULAR	0	0
1021	40	12/14/ 1	12/14/ 1	12/15/ 5	REGULAR	0	0
2121	30	12/15/ 5	12/15/ 5	12/15/11	OVER T.	0	45
2021	30	12/15/11	12/15/11	12/18/11	OVER T.	0	0

MIN. TOTAL VARIABLE COSTS:

USING THE LPTM RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
1121	0	4147	2959	0	24	0	7130
1021	1242	6739	5418	0	28	0	13427
2121	1242	6739	450	600	0	0	9031
2021	0	0	468	1600	39	0	2107

TOT.MIN.V. COSTS = $ 31695

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE THE MINIMUM POSSIBLE V. COST OF THE WHOLE ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 1 DATA

SET UP TIME HRS. NORMAL	SET UP TIME HRS. MAXIMUM	R.TIME HOURS	O.TIME HOURS	WORKING DAYS/WEEK	UNAVAL-ABILITY FRACTION	COST FACTORS IDLE T.	COST FACTORS OVER T.
.50	1.25	8	8	5	.00	3.00	1.50

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
1211	120	12/11/ 3	12/11/ 3	12/13/ 0	REGULAR	0	0
2211	120	12/13/ 0	12/13/ 0	12/14/ 4	REGULAR	0	0

MIN. TOTAL VARIABLE COSTS:

USING THE SPTM RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
1211	4147	0	5184	0	0	0	9331
2211	5184	0	2268	0	0	0	7452

TOT.MIN.V. COSTS = $ 16783

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE
THE MINIMUM POSSIBLE V. COST OF THE WHOLE
ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM
IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 2 DATA

SET UP TIME HRS. NORMAL	MAXIMUM	R.TIME HOURS	O.TIME HOURS	WORKING DAYS/WEEK	UNAVAL-ABILITY FRACTION	COST FACTORS IDLE T.	OVER T.
.25	.75	8	8	5	.00	2.20	2.00

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
2121	30	12/13/ 7	12/13/ 7	12/14/ 5	REGULAR	0	0
2021	30	12/14/ 5	12/14/ 5	12/15/ 5	OVER T.	0	0
1121	80	12/15/ 5	12/15/ 5	12/19/ 6	OVER T.	0	0
1021	40	12/19/ 6	12/19/ 6	12/20/ 2	OVER T.	0	0

MIN. TOTAL VARIABLE COSTS:

USING THE SPTM RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
2121	0	0	5637	0	24	0	5661
2021	18278	8100	47993	3200	0	0	77571
1121	16665	9720	0	3200	0	0	91678
1021	0	0	0	1600	0	0	11895

TOT.MIN.V. COSTS = $ 186805

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE
THE MINIMUM POSSIBLE V. COST OF THE WHOLE
ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM
IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 1 DATA

SET UP TIME HRS.		R.TIME	O.TIME	WORKING	UNAVAL-ABILITY	COST FACTORS	
NORMAL	MAXIMUM	HOURS	HOURS	DAYS/WEEK	FRACTION	IDLE T.	OVER T.
.50	1.25	8	8	5	.00	3.00	1.50

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
2211	120	12/11/ 0	12/11/ 0	12/12/ 5	REGULAR	0	0
1211	120	12/12/ 5	12/12/ 5	12/14/ 1	REGULAR	0	0

MIN. TOTAL VARIABLE COSTS:

USING THE FIFO RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
2211	4147	0	5184	0	0	0	9331
1211	2995	1512	3110	0	0	0	7617

TOT.MIN.V. COSTS = $ 16948

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE THE MINIMUM POSSIBLE V. COST OF THE WHOLE ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM IS CHOSEN TO BE PROCESSED FIRST ON STATION

WORKSTATION # 2 DATA

SET UP TIME HRS. NORMAL	MAXIMUM	R.TIME HOURS	O.TIME HOURS	WORKING DAYS/WEEK	UNAVAL-ABILITY FRACTION	COST FACTORS IDLE T.	OVER T.
.25	.75	8	8	5	.00	2.20	2.00

TIME TABLE

ITEM ID	QUANTITY NEEDED	ARRIVAL M. D. H.	STARTING M. D. H.	FINISHING M. D. H.	WORKING HRS.	QUEUING HRS.	IDLE T. HRS
1121	80	12/ 6/ 4	12/ 6/ 4	12/12/ 4	REGULAR	0	0
2121	30	12/12/ 4	12/12/ 4	12/13/ 2	REGULAR	0	0
2021	30	12/13/ 2	12/13/ 2	12/15/ 2	REGULAR	0	0
1021	40	12/14/ 1	12/15/ 2	12/18/ 6	REGULAR	25	0

MIN. TOTAL VARIABLE COSTS:

USING THE FIFO RULE

	INVENTORY COSTS DUE TO: WAITING	H.TWIN	EARLINESS	OVER T. COSTS	IDLE T. COSTS	DELAY COSTS	TOTAL COSTS
1121	0	4147	2959	0	24	0	7130
2121	1242	6739	5418	0	28	0	13427
2021	2076	0	4368	0	15	0	6459
1021	1200	0	864	0	0	0	2064

TOT.MIN.V. COSTS = $ 29080

PLS. NOTICE THAT THE ABOVE COSTS ACCUMULATE THE MINIMUM POSSIBLE V. COST OF THE WHOLE ITEMS AT A GIVEN PERIOD WHEN A CERTAIN ITEM IS CHOSEN TO BE PROCESSED FIRST ON STATION

TASK C: AN ARTIFICIAL INTELLIGENCE APPROACH TO PRODUCTION SCHEDULING IN FLEXIBLE MANUFACTURING SYSTEMS

CHAPTER I

INTRODUCTION

A Flexible Manufacturing System is a network of computer controlled, semi-independent workstations comprised of numerically controlled machine tools which are designed to simultaneously process a number of part families at low to medium volumes. This network is linked together by automated material handling devices, and controlled by a central computer system. The number of machines in the system usually falls in the range from 2 to 20. The material handling system may consist of carousels, conveyors, carts, robots, automatic guided vehicles, or a combination of these. The control computer which directs the flow of parts through the system is essentially a traffic coordinator. Through extensive computer control and efficient scheduling of the FMS, it is possible to achieve a high level of productivity typically associated with well balanced transfer line and at the same time retain the flexibility of the job shop environment.

The benefits associated with the use of the FMS are identified as follows [3]:

1) High capital equipment utilization due to the high efficiency achieved by having the computer to automatically schedule parts to machines as soon as they are free.

2) Reduced capital equipment costs because of the need for fewer machines in the FMS to handle the same workload.

3) Reduced direct labor costs since machinists are not needed to operate machines which are under computer control.

4) Reduced work-in-process inventory and lead time as a result of 1) the concentration in a small area of all the equipment required to produce parts, 2) the reduced number of fixtures required to produce parts, 2) the reduced number of fixtures required and the number of machines a part must travel to, and 3) efficient computer scheduling of parts.

5) Responsiveness to changing production environments which is attributed to the inherent flexibility of the FMS to manufacture different products.

6) Ability to maintain production, since an FMS can be designed to degrade gracefully when one or more machines fail.

7) High product quality due to the high level of automation, reduction in the number of fixtures and the number of machines visited, better designed permanent fixtures, and increased attention to part/machine alignment.

8) Operational flexibility since in some systems the FMS can run practically unattended.

9) Capacity flexibility because of the fact that new machines can be easily added to the FMS as demand increases.

There are, however, a number of problems associated with an FMS. At the design and justification stage, two basic principles have to be met. One is that the required production of parts must fall in the mid-volume range. The other is that these products should share some common characteristics that will allow them to be grouped into families, while they are not required to have the same shape or geometry. Usually, a group technology concept is applied at this stage to select a subset of product families for the system and to decide on workstations of each type to balance the system utilization. At operation stage, production planning and scheduling, sequencing, and shop door control are all important issues. While Materials Requirements Planning II (MRP) has been well developed to serve production planning functions and some shop floor control systems are commercially available, production sequencing and scheduling are still at stake, although it has received widespread attention since its inception in the early 1970's.

The FMS scheduling and sequencing problem is very complex because simultaneous schedules have to be determined for each machine, and different parts and cutting tools need to be transported from one work station to the next, so as to take advantage of the systems flexibility and to assure productivity and system utilization. Specifically, the following scheduling decisions have to be made at the operation stage:

1) Select the new part to be released into the system.
2) Select the cart to mount the part.
3) Select the workstation, among the choices available, to perform a requested operation.
4) Select the part to be processed next from the queue at the workstation.

These decisions are commonly subject to such factors as machining time, machine and tooling availability, traffic control, etc., which further contribute to the complexity of the problem.

Due to the complexity of FMS scheduling and the fact that the scheduling problem is not well structured, a lot of heuristic rules and control strategies have been borrowed from job shops and tested in FMS environments. As shown in various studies, unfortunately there is no rule or control strategy which works sufficiently well or out-performs others for all FMS environments. Human schedulers and conventional computerized approaches have been overburdened by the complexity.

Recently the development of Artificial Intelligence (AI) techniques lead to a new direction of solving this problem. AI is concerned with designing computer systems that imitate certain characteristics of human thought such as the ability to reason, solve problems, learn from experience, and understand ordinary human language. Among the AI applications Expert Systems (ES) is an ideal tool for solving problems.

Expert Systems are concerned with the automation of tasks that are usually performed by specially trained people, or "experts." Expert systems differ from pure AI research in that the primary goal of expert systems is to consistently duplicate the results of a human expert, instead of understanding the basic mechanisms used by that person to arrive at a given result. Expert or knowledge-based systems are designed to compile the experiences of any number of experts in a given field into a set of rules. These rules are then used to draw inferences and to give the user a suggested course of action to take in a given situation (or have it carried out automatically). Expert systems differ from traditional programs in that traditional programming emphasizes procedural instruction for the computer, whereas the focus of expert systems is on the acquisition and organization of knowledge bases.

Figure 1 shows the components of an ideal expert system [5,10]. So far there is no system which incorporates all the components, but one or more of them is incorporated in most expert systems. The rules, facts, and information about the problem being solved are contained in the "Knowledge Base." The "Inference Engine" is a control mechanism which defines the problem solving approach, and the "Blackboard" is used to keep track of the intermediate results and decisions made by the system. It is important to note that in an expert system there is a separation of the inference engine from the rules or data items contained in the knowledge base. This is another aspect of expert systems that distinguishes them from conventional programs [10].

user

language processor

knowledge base

justifier

blackboard

inference engine

Figure 1. Components of an Ideal Expert System

The expert system approach presented in this paper is based on the more general concept of the production system. A production system consists of three basic components, namely a set of rules (or knowledge base), a global data base, and an interpreter for the rules for inference systems.

A rule in a production system can be regarded as an ordered pair of symbols with a left hand side and a right hand side. Generally, one side of a rule is evaluated with reference to the database, and if it evaluates to true, the action specified by the other side is performed. The data base is a collection of symbols to reflect the state of the world, but the interpretation of these symbols depends in large part on the nature of the application. The interpreter is a select-execute loop in which the rules are scanned until one is found that is applicable to the current state of the database. It is then executed, updating the database, and scanning resumes.

Production systems are well suited for multiple, nontrivially different problems with independent states that consist of a process composed of independent actions requiring only limited communication between them.

To varying degrees, the following characteristics are shared by all rule based production systems [2, 10]:

1) Rules as primitive actions
2) Indirect, limited channel of interaction
3) Constrained format for rule representation
4) Modularity
5) Poor visibility of behavior flow

Production systems have wide variations in their form, knowledge content, control cycle architecture and system extensibility capabilities, but the fundamental methodology provides a convenient framework for structuring and specifying the large amounts of knowledge available in the area of expert systems.

In this study, an ES technique will be employed to solve two important scheduling problems or daily encounters on an FMS. They are:

1) When to release which type of raw material to the system for processing.
2) Which operation to process first on each workstation.

The study considers the utilization of the machines as a factor in priority releasing rules, due date rules, minimum cost rules and flextime scheduling rules as well as a newly developed heuristic algorithm, the minimum Cost Factor Releasing Rule (MCFR) [8] in which all these constraints are under consideration. The model is based on an adaptive, adjusted manufacturing lead time decision rule with look-ahead and look-back capability. Minimizing production costs is used as a measure of performance of the model.

The next section of the study discusses prior research work related to the scheduling problem and current research in this area. Section 3 provides a general introduction to the important concepts of CML and discusses its suitability for the FMS scheduling problem. Section 4 discusses the logic design and development of the prototype system.

Section 5 demonstrates the working of the prototype system through a small example. Section 6 concludes the paper and discusses possible future research in this area.

CHAPTER II

REVIEW OF AI APPLICATIONS IN FMS

Numerous studies have been done on the traditional job shop and hence many simple heuristic rules have been proposed for the purpose of determining which part to schedule next at a workstation. They were basically developed as general purpose rules applying to the majority of situations occurring in the job shop environment [7, 10]. These rules, however, are too simple to handle the dynamics of the flexible manufacturing system.

The Intelligent Scheduling and Information System (ISIS-II) [4,10] was the first large scale AI-based scheduling system developed for the job shop. It represented an improvement over other methods because of its ability to represent different types of constraints and to selectively relax these constraints.

The PATRIACH system is an integrated planning and scheduling system. Developed by Morton et al [6,10] it incorporates a hierchical structure at four levels, has decision support capability, uses advanced knowledge representation and uses practical large scale heuristics.

As mentioned above, Saber [8] has developed a heuristic algorithm, the Minimum Cost Factor Releasing Rule which addresses the issues of when to release raw materials to start processing jobs on an FMS and which operation to process first on the workstation. He has simulated a hypothetical FMS in which minimizing the production costs is the main objective, and has compared the results to those obtained by some popular existing methods such as First In First Out (FIFO), Shortest Processing Time (SPT), and Longest Processing Time (LPT).

CHAPTER III

INTRODUCTION TO CML

The Cell Management Language [12] is a new language that can be used to build expert systems. CML is a language oriented relational database system in which the most powerful and widely used functions are those concerning natural language processing. These language oriented capabilities are what differentiate CML from other relational database systems. The commands used in CML allow it to: manage protocol from a variety of different machines, produce natural language interfaces for database entry programs, and operate as a rule-bases system not necessarily related to machine control. Natural language processing has a wide range of application areas, including systems control. By coupling a natural language interface with different types of devices, a range of possible systems may be produced including those that [13]:

1) Provide answers to questions by accessing large databases.
2) Control complex systems such as industrial robots, power generators, or missile systems.
3) Furnish expert advice about mechanical repairs, medical problems, mineral exploration, the design of genetic experiments, or investment analysis.

Area 3 involves the integration of natural language processing with expert systems. Some limited demonstration programs have already been produced, but much work remains to be done.

One disadvantage of using natural language as the command language for controlling computer systems is that English is poorly suited to machine interactions involving the extensive manipulation of numbers.

Data is easily represented, stored and controlled in CML due to the anatomy of the CML database. The database is composed of workspaces, tables, and items. As shown in Figure 2, the relationship between these items and the database is as follows:

1) The database contains workspaces
2) Workspaces contain tables
3) Tables, which are made up of rows called entries and columns called fields, are composed of items.

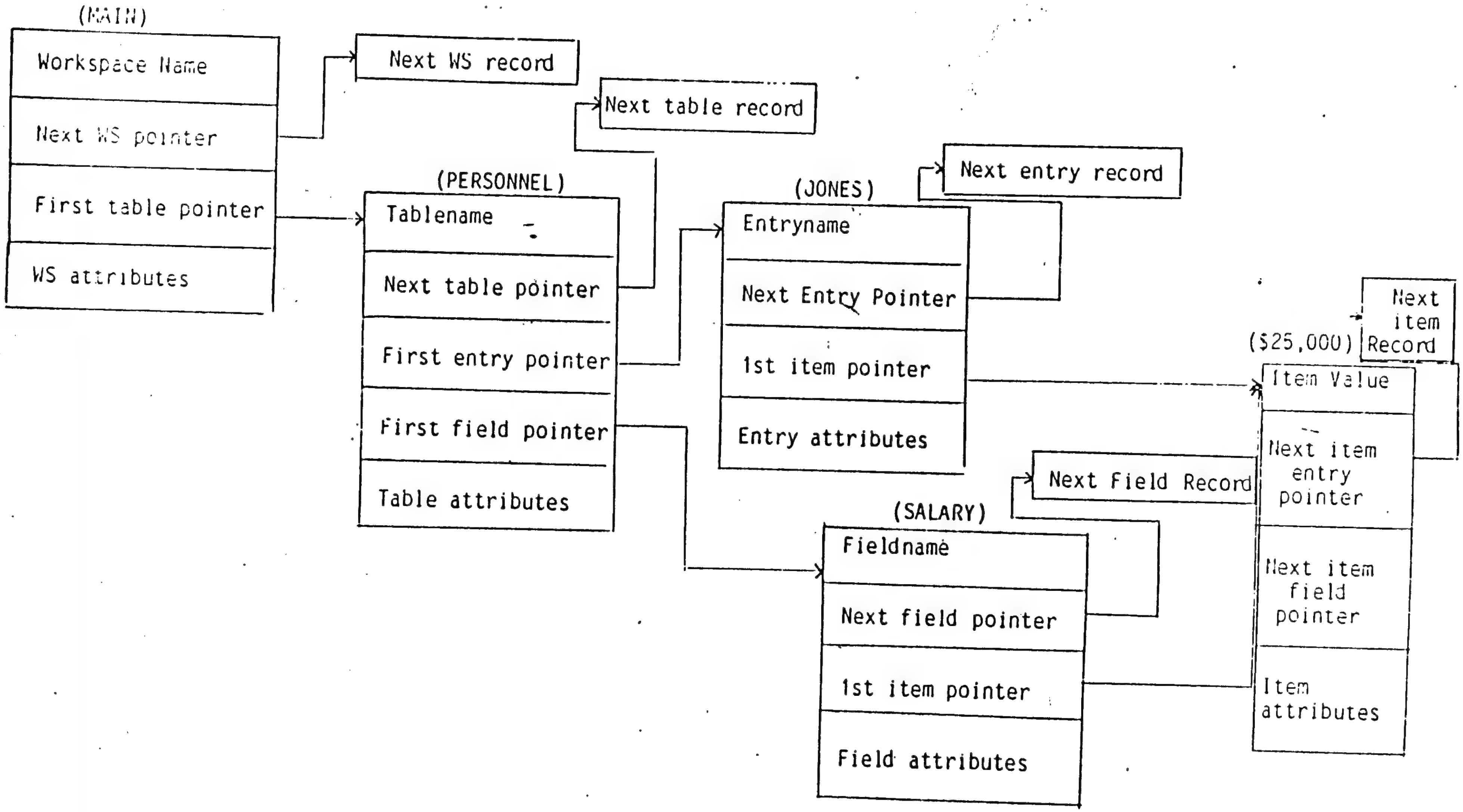
Workspaces provide a means of organizing a set of tables which are grouped together by purpose. Each workspace can have its own set of tables and a special set of workspace attributes that define the working environment.

Tables are created to hold the individual database items. There are five classifications of tables in the CML database:

1) Lexical tables define legal words of a vocabulary and their syntactic category. For example, "verb" is a syntactic category and the words "run, jump, and kick" fall into this category.
2) Syntactic tables define the arrangement of words and phrases in a language.
3) Semantic tables define a set of rules which determine how information provided to the system is interpreted.
4) Functional tables define the set of tables which represent the functions needed to carry out actions initiated by the satisfaction of conditions stated in the rules.
5) Data tables define a set of tables which contain data concerning input into programs which constitute the application. Figure 3 shows a generic model of a CML table.

Items are the basic building blocks of the CML database, and may be data or instructions. Each item has a set of 10 attributes that describes its syntactic qualities.

FIGURE 2
ANATOMY OF THE CML DATABASE



All instructions and data in CML programs exist as items within tables.

Tablename	Field1	Field2	Field3
Entry1	Item11	Item12	Item1n
Entry2	Item21	Item22	Item2n
:	:	:	:
:	:	:	:
Entrym	Itemm1	Itemm2	Itemmn

Figure 3. A Generic Model of a CML Table

In order for CML to be executed, a grammar and a vocabulary must be created. The vocabulary in CML is defined in a tabular form where the table name defines a lexical class and the entrynames (words of a vocabulary) define members of that class.

Grammar tables in CML list the order and form in which words or phrases of a language may appear in a sentence that is input by the user. Items of a grammar table can be matched with an input sentence through a lexical match. This occurs when a grammar item is the name of a lexical class (e.g. noun) and the input sub-string is a member of that lexical class.

The pathname mechanism provides the system user with the ability to address database objects. The format of the pathname to address a specific item is "tablename: entryname:fieldname. In the generic table of Figure 3, the pathname "Tablename:Entry2:Field1" would address Item 21. To address a field, the correct form of the pathname would be "tablename:fieldname," and to address an entry, the pathname would be "tablename:entryname."

Lexical and syntactic tables in CML are required to "parse: input. Parsing is the breaking up of an input sentence into its legal lexical components. When parsing takes place, a table with the name $Parse will be created. In will contain each lexical category that makes up the input sentence and the components of the sentence with which they were matched. As a result of being parsed, the input sentence and $Parse table become a syntactic reading without meaning or effect, and therefore meaning must be supplied by a semantic table which will define a set of rules that determine the interpretation of the input data.

Semantic tables define the "meaning" of a language through a set of logical rules. In CML, semantic rules establish the conditions under which certain functions are evaluated. Each entry in a semantic table is a rule, and each condition or clause in the rule must be satisfied by being matched against the given data before that rule can be fired.

When each clause of a rule matches the data and the rule is successively fired, a table containing action messages is executed. These action messages suggest to the system user what action to take next in the system. Each action message is attached to a specific rule, therefore each time a rule is fired, an action message corresponding to that particular rule is printed on the screen.

At this point there is no formal published documentation of CML, but the language and the parsing mechanism have been discussed in the manual prepared for the Westinghouse Electric Corporation by Wallestein [12].

To address the problem of when to release raw materials to start processing a job, a flexible lead time approach was used by applying the Rough Cut Capacity (RCC) technique, which is used to estimate the production capacity for operations. The MCFR was formulated to satisfy the problem of which operation to process first on the workstation.

This is a decision rule which releases ready operations into the workstations based on minimum expected processing costs of all the possible arrangements of ready operations at each workstation. The first ready operation in the arrangement that has the minimum expected processing cost will be selected as the best candidate to be processed first on the workstation.

In this paper, the MCFR rule developed by Saber [8] will be demonstrated from an ES approach using the Cell Management Language (CML), and the reader will be introduced to the basic concepts of CML and its application to scheduling on an FMS.

Approaching this problem through the use of CML involves several requirements:

1) Building several small databases containing each level of the specified Bill of Materials (BOM)
2) Building a database containing due date information
3) Establishing a database of individual workstation information
4) Developing rules for determining the minimum total variable production costs (which are used to apply the MCFR rule
5) Developing rules for determining arrival time and maximum expected lead-time
6) Establishing mathematical equations
7) Creating suitable action messages

These requirements will be discussed later in the paper.

The basic assumptions of the MCFR heuristic model [8] are as follows:

Assumptions concerning jobs:

1) Each job consists of specified operations, each of which is performed by one workstation.

2) Each operation can be in one of the following states during its processing period:

"W" - Waiting to be processed

"R" - Ready to be processed

"P" - Processing

"C" - Completed

3) Twin operations are not allowed to be processed at the same work station.
4) Each operation's set up time is flexible.
5) Each job has a prescribed bill of materials.
6) Each operation has specified machining time on each workstation.
7) Each item has a standard identification code.
8) Inventory cost factor is available for each item at any workstation.
9) In case of defects, jobs are processed to completion using the most available item is stock.

Assumptions concerning workstations

1) Each workstation has its own specified capacity.
2) A workstation unavailability factor is known with certainty and available for each work station for input into the model.
3) Each workstation can process four different operations simultaneously.
4) Set up times are known or can be determined for each station.
5) Minimum set up time for each station is zero.
6) No preemption is allowed.
7) Infinite storage capacity is assumed.
8) The terminal workstation performs the last operation of the jobs.
9) Over-time cost factor is available for each workstation.

Limitations of the model [8] include the use of a maximum of 9 workstation in the computer program, and the use of a maximum of two different jobs simultaneously, each of which could contain a maximum of 9 operations excluding the last one.

Limitations associated with expert systems in general include the following [13]: overly narrow domains of expertise; inadequate communication channels with the user; inability to represent certain kinds of knowledge easily; and difficulty in building and modifying the knowledge bases on which these systems are based. In addition, the systems which have been developed to date all suffer from several serious weaknesses which fall into the categories of system development limitations, competence limitations, and use limitations.

Set Work Station Index [i = 1]

Is the work station available now?

No

Identify the work station constraints and variable values. Then calculate and identify the set of "R" on it.

Calculate min. EPC of the whole possible arrangements of "R" on the work station, when the first position is fixed with one of the "R" 's.

Repeat the last iteration for the same " R " operations (R-1) times, by fixing another " R " operation on the first position each iteration.

Sort the min. EPC's & select the min. Then select the first operation of the arrangement which has the min. EPC.

Change the status of the selected operation and start processing. And remove that operation from " R " set.

Are there more stations left?

Yes

Increase work station # by 1 i.e. i=i+1

No

All operations completed?

Yes

No

Fig 4 : Logic flow chart of the (MCFR) rule.

Start

Identify the due date for a given job.

Estimate the processing time of the last operation in the given job.

Apply RCC rule to estimate the last operation's child schedule due date.

Calculate the EPT of each child predessors and do the next iterations for each predessor individually till pointer A.

items due dates are estimated?

No

Estimate the new predessor(s) due date: NCHDD = CHDD-EPT

Yes

Estimate the arrival time (ATM) of each operation on it's work station.

Yes

More jobs?

No

Fig: 5 Logic flow chart of step (1).

CHAPTER IV

SYSTEM DEVELOPMENT

The logic flow charts of the RCC and MCFR rules are shown in the figures 4 and 5 respectively [8]. In order to apply the MCFR and RCC rules, databases must be built and rules must be determined to carry out the tasks specified at each level.

A sample model of a small Bill of Materials database in tabular form is shown in Figure 6.

BOM	Parent item	Twin item	Mach. hrs.	Inv. fact./item	cost	% age of unit prod.	qty need	ID #
Item 1	10	11	.20	1.20		15	.30	2121
Item 2	20	21	.10	1.20		60	60	2211
Item 3	30	31	.40	1.20		35	80	1121
Item 4	40	41	.10	1.20		45	90	1211

Figure 6. Sample Model of a Small CML Database

This type of database can be created and updated by interactive input from the system user upon a prompt from

the system, and can then be used throughout the execution of the program to readily provide whatever information contained in it is needed. This type of data storage saves a great deal of time and space in the program since the user does not have to repeatedly input specific data items when needed in the program E. Instead, this information is simply pulled from the database. Tables containing workstation and due-date data can also be built in this manner. Taken together, this set of tables would form the system's global database.

Rules that will be used to make the final decision on which operation to process first on the workstation will follow the logic of those shown in Figure 7. These rules are needed at several decision points in the MCFR algorithm. For example, before a final decision can be made, lowest total variable production costs (TPVC), earliest arrival times, and maximum expected lead-times (ELT) must be chosen based on the provided rules. The set of all rules taken together form the knowledge base of the system.

```
1)  IF    TPVC11 is greater than TPVC12
    THEN  retain the value of TPVC12
2)  IF    TPVC11 is less than TPVC12
    THEN  retain the value of TPVC11
3)  IF    TPVC21 is greater than TPVC22
    THEN  retain the value of TPVC22
4)  IF    TPVC21 is less than TPVC22
    THEN  retain the value of TPVC21
```

Figure 7. Sample rules for the MCFR Algorithm

After rules are established, it is necessary to write math equations using the proper CML format. These equations will be used to determine quantities such as total production variable costs, regular and overtime costs, expected lead times, etc. The format of these equations is illustrated in Figure 8.

Functions 1 through 4 are used to write equations to perform addition, subtraction, multiplication and division respectively. In each function, <pathname 1> is the address for the result of the operation being performed, the <pathname 2> and additional <pathname>s are the addresses of tables to be summed, subtracted, multiplied, or divided. Again, a pathname is the address of an item and consists of a tablename followed by an entryname followed by a fieldname.

1) plus, <pathname 1>,<pathname 2>[,<pathname 3>,...]
2) minus, <pathname 1>,<pathname 2>[,<pathname 3>,...]
3) times, <pathname 1>,<pathname 2>[,<pathname 3>,...]
4) divide, <pathname 1>,<pathname 2>[,<pathname 3>,...]

Figure 8. Some CML Math Functions

An example of how an equation can be transformed into the CML format follows. Consider the equation:

Exp. lead time (ELT) = Est. delivery date (EDD) - curr. time (TNOW) Suppose the system user wants the value for estimated lead time to be stored in a table called A. the value of current time is located in table C, the correct CML equation would be:

minus, A:ELT:Value, B:EDD:Value, C:TNOW:Value

In this case the operation is subtraction, and TNOW is subtracted from EDD to obtain the value of ELT. ELT will be stored in Table A.

The final requirement that must be considered in creating the prototype system is creating action messages. As mentioned earlier, when each clause of a rule matches the data, thereby firing it, an action message corresponding to the rule is printed on the screen, which suggest to the user what scheduling decisions would be the wisest to make. A set

of sample action messages can be seen in Figure 9. These messages correspond to the rules of Figure 7. Action message 1 refers to the system user that since, in rule 1, the total production variable cost was lower for item 2 when it was scheduled before item 1, it would be wise to process item 2 on workstation 1 first.

The remaining messages follow the same logic.

1) Process item number 2 on workstation 1 first
2) Process item number 1 on workstation 1 first
3) Process item number 2 on workstation 2 first
4) Process item number 1 on workstation 2 first

Figure 9. Action Messages

CHAPTER V

PERFORMANCE OF THE PROTOTYPE SYSTEM

Once all the databases, rules, math equations and action messages are established, CML can be used to code and test the system. A sample run of the prototype system being developed is shown in Figure 10. The system is an interactive model which shows the user what kinds of inferences it makes in order to arrive at solutions. The following sample run shows how a small CML database can be interactively built by the user. The type of database that would be built would be similar to the one shown in Figure 6.

```
Enter the number of items in the first level BOM>>> 2.
Enter the first item's ID number>>> 2021.
Enter the machine hours per item>>> .50.
Enter the inventory cost factor per item>>> 1.20.
Enter the percentage of unit product>>> 25.
Enter the quantity needed>>> 30.
Enter the Complete item ID #>>> 2021-3.
Enter the next item's ID number>>> 1021.
```

Figure 10. Sample Run of the Prototype Scheduling System

Although the samples shown in Figures 6, 7, and 8 are very simple, they still serve to illustrate the representational power and inference capabilities of CML.

The attached partial program shows how several of the key concepts discussed above can be used to create an expert scheduling system using the MCFR algorithm.

Performance of the proposed system has not yet been studied since the prototype system is not yet complete. However, a comparison of the proposed method to the method used by Saber [8] seems to indicate that a rule based approach has definite advantages over a triditional programming approach.

A rule based approach was chosen because production scheduling is well defined by a set of event-driven activities which operate on a set of relevant system state variables, which are contained in the global database. Such activities cooperate to solve the complex, ill-structured FMS scheduling problem, a task that logically requires a certain amount of expert knowledge and reasoning capability since direct algorithmic solutions are not always feasible [1].

Traditional procedural programming languages such as Fortran, which was employed by Panawalker and Iskander [7] in approaching the scheduling problem, have commonly been used to implement these systems. While the efficiency of these implementations has been widely acknowledged, they cannot adequately satisfy many other essential requirements, especially transparency, modularity and flexibility. In procedural languages, the knowledge representation and use are embedded in the program's control flow, and adding, deleting, or updating the knowledge base is time consuming for even a skilled programmer. These strict programming techniques are alleviated by the use of a rule based approach.

CHAPTER VI

CONCLUSIONS AND SUGGESTIONS

If the factory of the future is ever to be fully obtained the brains of design, manufacturing and production engineering experts must be probed and their expertise transferred into a knowledge base. It is expert systems that will make a factory self-adaptive and intelligent. Eventually, expert systems will be expected to outperform human experts due to improved standardization and the limits of human cognitive capabilities [10]. There must also be a rational computer based expertise to replace all of the operating systems manned by people.

The future factory must not only have the intelligence of the past, but be capable of integrating new methods and experience into the system [11].

In this paper, a new computer approach to scheduling on an FMS has been presented. Although CML is a brand new language, and there have been no published studies to date on its worthiness as an FMS scheduling tool, this language seems to hold promise in this area. It provides parsing algorithms for syntactic analysis of sentences and techniques for semantic interpretation, as well as mechanisms for storing relevant system state variables, and for establishing rules to form the knowledge base of the system. These characteristics of CML make it a potential candidate for many practical applications.

Suggestions for future research include scaling the prototype system up both in complexity and in the number of workstations, simultaneous jobs, and operations that the program can accommodate.

The knowledge content of an expert system is the key to its successful implementation. Simulation is a useful tool for developing an improved, more realistic knowledge base for the expert system. Interactive and graphics simulation packages offer exciting possibilities for understanding more thoroughly the working of an FMS. Incorporating existing expert knowledge with results from active experimentation on simulation models opens the possibility of developing improved knowledge bases for expert systems introduced by Subramanyam and Askin [10].

REFERENCES

1. Bruno, ., Elia, A. and Laface, P., "A Rule-Based System to Schedule production," Computer (July 1986), P.33.

2. Buchanan, B.G. and Shortliffe, E.H., Rule Based Expert Systems, Addison-Wesley Publishing Company, Reading, Mass., (1984)

3. Draper, C.S., Laboratory Staff, Flexible Manufacturing Systems Handbook, Noyes Publications, Park Ridge, New Jersey (1984).

4. Fox, M. S., Allen, B. and Strohm, G., "Job-Shop Scheduling-An Investigation in Consraint-Directed Reasoning," Proceedings NCAI, Pittsburgh, (1982) p. 158.

5. Hayes-Roth, F., Waterman, D.A. and Lenat, D.B., "Building Expert Systems," The Teknowledge Series in Knowledge Engineering, Addison-Wesley Publishing Co., Inc. (1983).

6. Morton, M.E., Fox, M.S. and Smunt, T., "A Planning and Scheduling System for Flexible Manufacturing," Proceedings of TIMS-ORSA Conference on FMS (August 1984) pp. 314-326.

7. Panawalker, S.S. and Iskander, W., "A Survey of Scheduling Rules," Operations Research, Vol. 25, No. 1, (Jan-Feb 1977), pp. 45-61.

8. Saber, H.M., "A New Heuristic Approach to Multi-Level Production Scheduling Flexible Manufacturing Systems," M.S. Thesis, Depart. of Industrial Engineering, N.C. A & T State Univ. (1985)

9. Shannon, R.E., Mayer, R. and Adelsberger, H.H., "Expert Systems and Simulation," Simulation (June 1985), p. 276.

10. Subramanyam, S. and Askin, R.G., "An Expert Systems Approach to Scheduling in Flexible Manufacturing Systems," Flexible Manufacturing Systems: Methods and Studies, A. Kusiak (Ed.), Elsevier Science Publishers B.V., North Holland, (1986).

11. Tou, J.T., "Design of Expert Systems for Integrated Production Automation," Journal of Manufacturing Systems, Vol. 2, No. 4, p. 155.

12. Wallerstein, R.S., "Cell Management Language Beginners Manual," Prepared for Westinghouse Electric Corporation by the Robotics Institute of Carnegie Mellon Univ. (Unpublished), (1985)

13. Waltz, D., "Artificial Intelligence, An Assessment of the State-of-the-Art and Recommendations for Future Directions," International Center, Leesburg, VA., (Jan 5-7. 1983)

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1.285000	2.245000	1.976192
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AREA	X-CENTRIOD	Y-CENTROID	I-XX	I-YY
.3353E+01	-.1330E+00	-.2390E+00	.1365E+02	.2627E+01